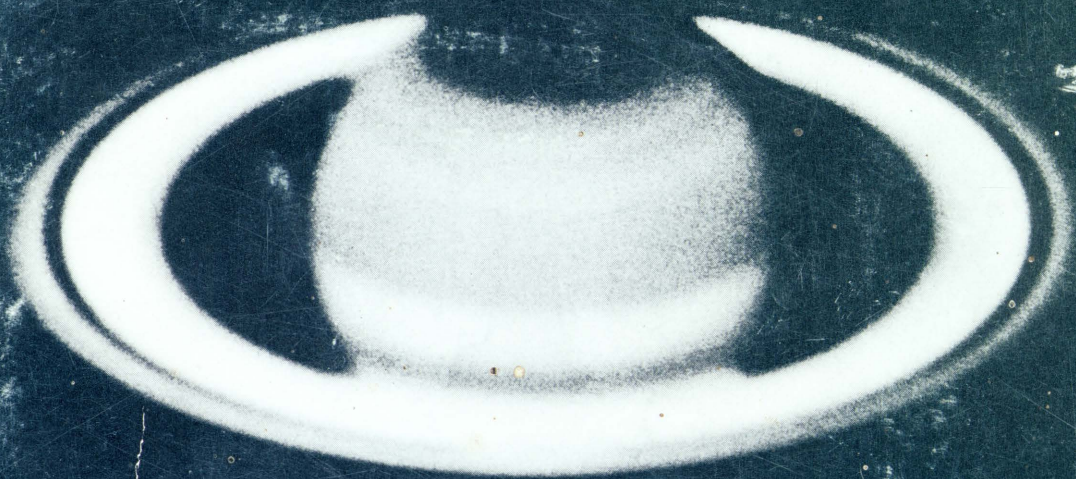

The Planets and Their Satellites

by

Franklyn M. Branley, Associate Astronomer
American Museum – Hayden Planetarium

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Activities and Photo Selections by
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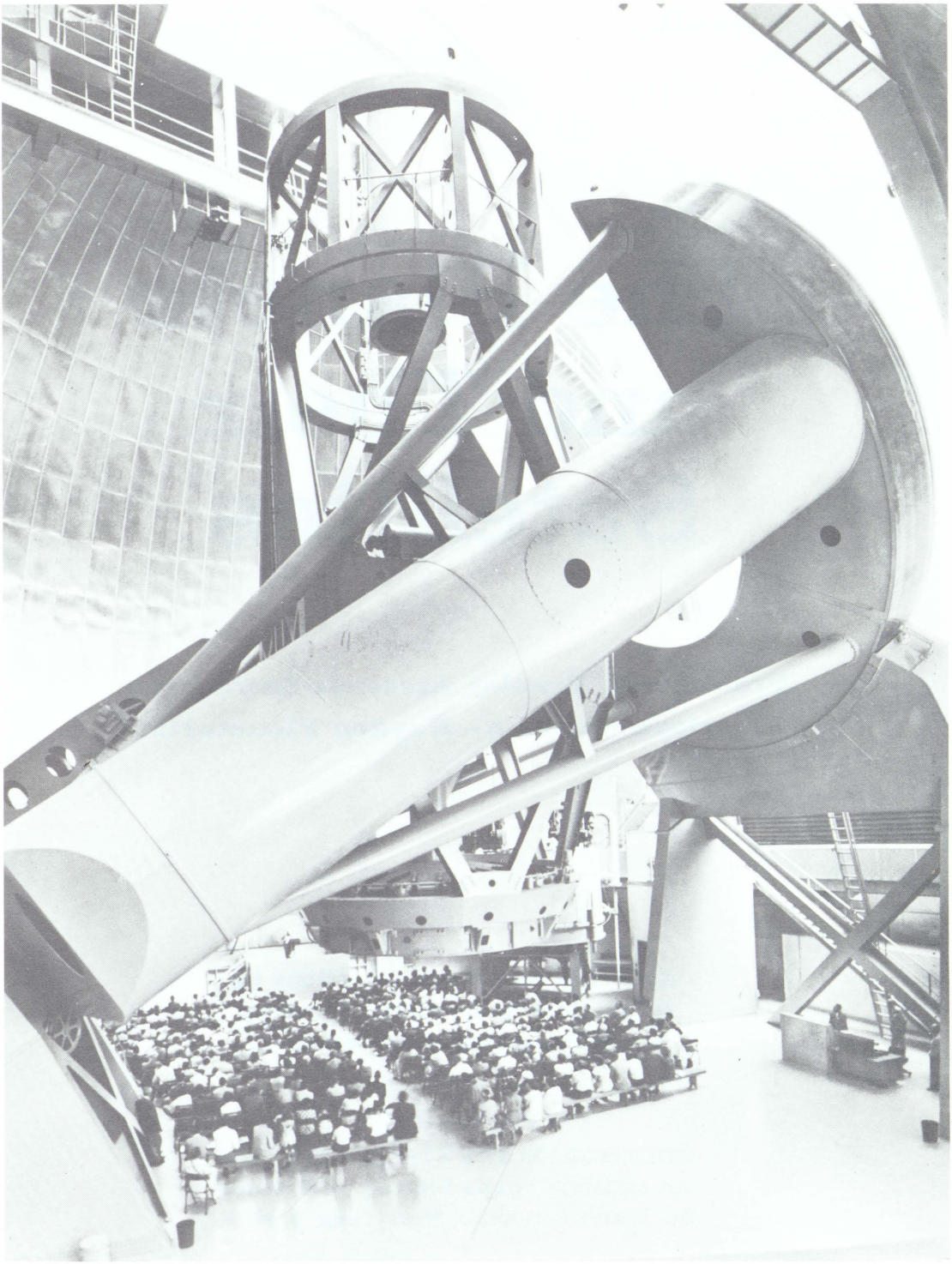
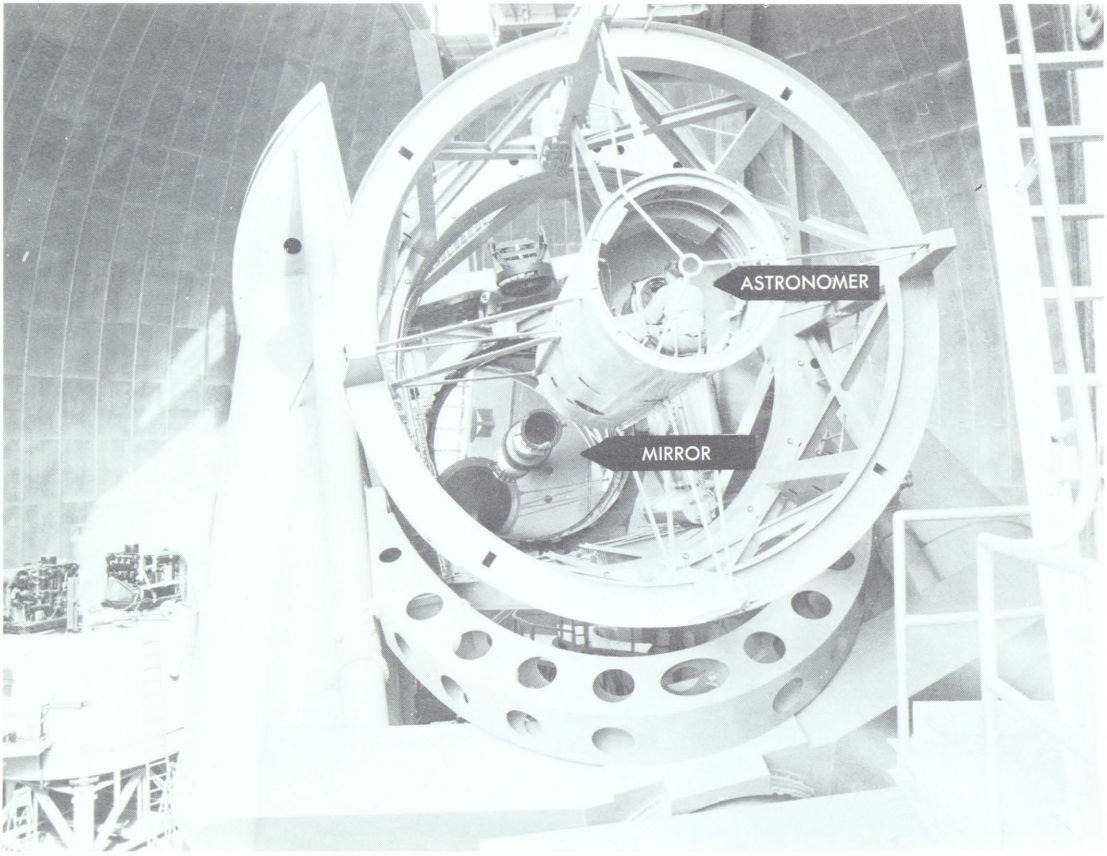


Some idea of the immense size of the large telescope at Mount Palomar may be obtained by comparison with the audience below it. (Mount Wilson and Palomar Observatories)

Reaching Into Space

Astronomers have two basic means of obtaining information. First, they have optical telescopes, instruments that gather in light. The largest is the great Hale telescope, the 200-inch reflector on Mt. Palomar in California. Telescopes such as this gather in light and lead it to photographic plates where it is recorded, or to spectrographs where it is analyzed and then placed upon film. Second, astronomers have at their command the vast possibilities of radio astronomy. In 1931 Jansky discovered radio astronomy quite by accident when he was investigating interference of international telephone communications systems. In 1960 the United States Government completed the largest radio telescope in America, the 140-foot disk at Greenbank, West Virginia. The range of the optical telescope is extremely limited—the Hale telescope (the 200-inch reflector) can capture light from formations that are two billion light years away. Radio telescopes have a much broader range; they may ulti-



The largest optical telescope in the world, at Mount Palomar, has a mirror 17 feet in diameter. The astronomer sits in a chamber inside the telescope and guides it so as to follow the stars while a photographic plate is exposed. After the photograph is developed, it is carefully studied and interpreted by astronomers. (Mount Wilson and Palomar Observatories)

mately be able to reach the boundaries of the universe.

All the information that astronomers have about the universe comes from active bodies, from bodies where energy is being created—that is, from the stars. Our sun is a star; it is the storehouse of energy for the entire solar system. We can look at the sun directly, and so get information by way of the light it sends to us. Or we can look at a planet of the solar system or one of the natural satellites of the planets and get information by way of sunlight which the planet or satellite reflects to us.

Stars, including our sun, produce light; planets and their satellites reflect sunlight.

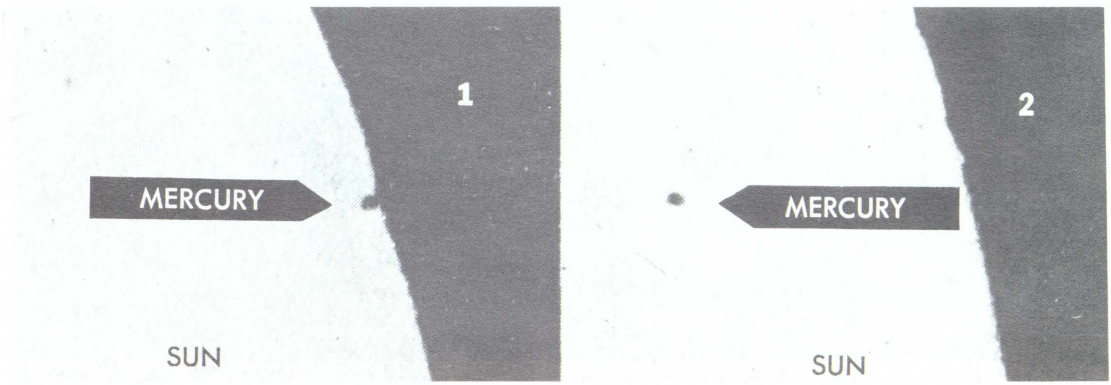
The Planets One By One

Mercury

Mercury is the smallest planet in the solar system. It is only 3100 miles in diameter. But this is not to say that Mercury has no claim to distinction, for indeed it has. Because Mercury is nearest to the sun, the planet must move rapidly in order to remain in orbit. The planet has a very short period of revolution around the sun; only 88 days. This means that a year on Mercury would be only 88 earth-days long. On Mercury, your age would be about four times what it is on earth—if you are 15 years old here on earth, you would be 60 years old if you were on Mercury.

If your age on Mercury were measured in days, you would be very young indeed, for a day on Mercury is 88 earth-days long. This planet revolves around the sun in 88 days, and it rotates on its axis in 88 days. As a result, the same half of Mercury is always toward the sun. You can see why this would occur if you follow these directions. Stand in the center of a room; turn around once so that you face all four walls of the room. Now place a chair in the center of the room. The chair represents the sun, and you represent Mercury. Move around the chair once, facing it at all times. While moving around the chair (revolving), you faced all four walls of the room in succession (you rotated). Both operations required the same length of time, so you faced the chair continually. So it is with Mercury and the sun.

The half of Mercury toward the sun is very hot indeed—around 700° F., which is hot enough to melt lead and tin, hot enough to set wood on fire. The half of Mercury away from the sun must be very cold indeed, for it would never re-



A *transit* (crossing) of Mercury (black spot) across the face of the sun. Why isn't this an eclipse?
(The American Museum-Hayden Planetarium)

ceive solar energy. The temperature of this half of the planet may be close to absolute zero—the coldest anything can be—around 459° F. below zero.

Between the sunlit side and the dark side of Mercury there is a region where the sun would alternately rise and set because of slight variations in Mercury's motions. But this would be a very limited region, and also a place of extremes.

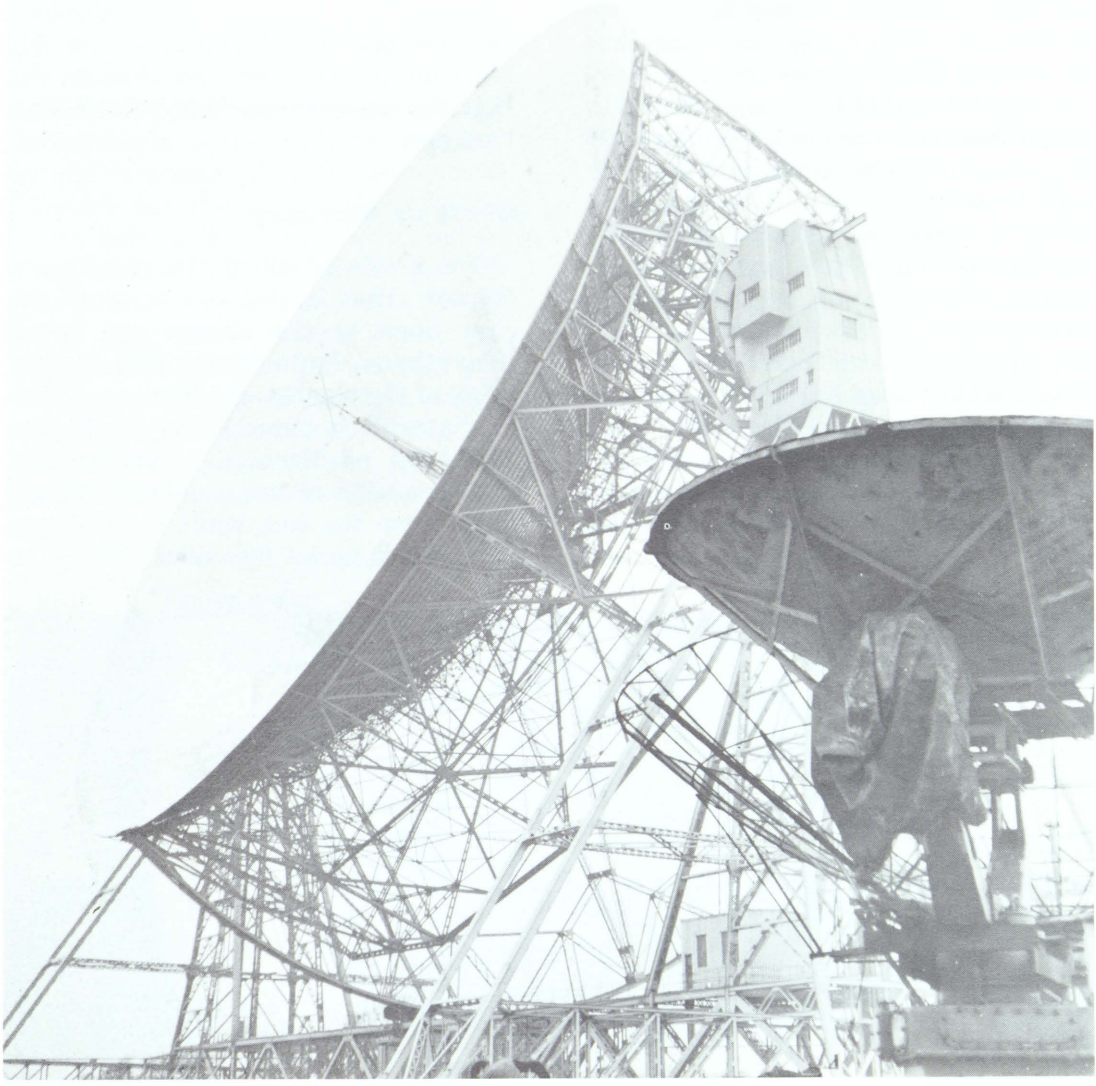
Even if one could withstand the temperatures on Mercury, he could not exist there, for the planet has no atmosphere. The mass of the planet is so low that there is a relatively low velocity of escape (velocity needed by an object to escape from the planet). Therefore particles in an atmosphere would have escaped from the planet. We have never observed any signs of an atmosphere on this planet. If Mercury ever did have an atmosphere, the chances are that the atmosphere disappeared long, long ago.

Orbit of Mercury

The orbits of all of the planets are ellipses. That is, they are flattened circles. Some of the ellipses are flatter than others. Pluto has the flattest orbit of all of the planets; the flatness of Mercury's orbit is second only to Pluto's. The orbit of Mercury is so flat that sometimes the planet is only 28,600,000 miles from the sun, while on other occasions it is 43,400,000 miles away. The

One direct effect of storms on the sun is the *aurora borealis* (northern lights), seen here as a glowing light in the sky. These lights are caused by streams of electrical particles that are shot out by the sun during periods of strong sunspot activity. Such storms often disrupt radio communication and may have other effects, as yet unknown.

(The American Museum-Hayden Planetarium)



This radio telescope at Jodrell Bank, England, 250 feet in diameter, picks up extremely faint radio signals from stars and galaxies far out in space. This new type of instrument enables astronomers to get important information that is not revealed by optical telescopes.

(Wide World Photo)

mean distance (average distance) of Mercury from the sun is 36,000,000 miles.

When a planet is close to the sun, it moves fast. When it is far from the sun, the planet moves more slowly. The velocity of Mercury around the sun is 35 miles a second when it is near the sun, and only 23 miles a second when it is at the greatest distance from the sun.

When Mercury is between the sun and earth, it is only 50,000,000 miles away from us. When the planet is on one side of the sun, and earth is on the directly opposite side, the distance from earth to Mercury is around 136,000,000 miles.

It is very hard to see Mercury be-

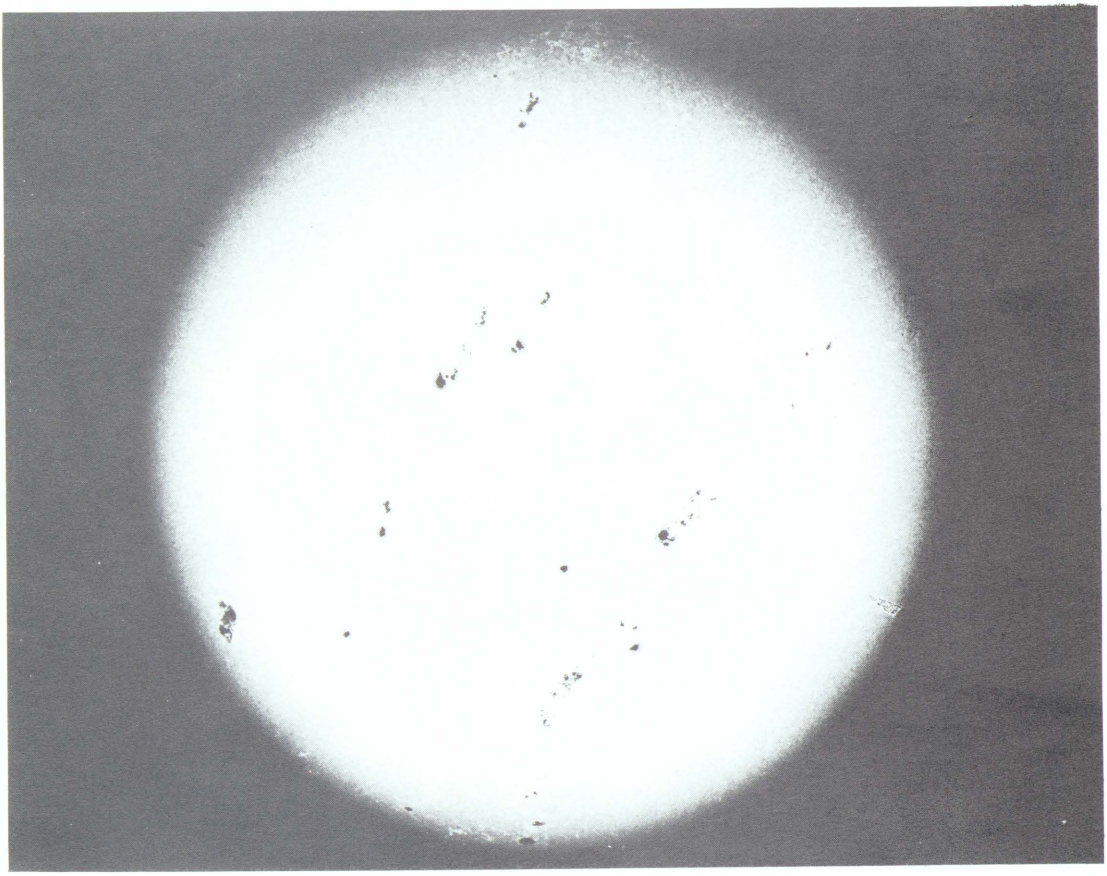
cause the planet is so close to the sun. In fact, many star gazers have never seen the planet. Even professional astronomers have difficulty seeing Mercury, although some astronomers have attempted to make sketches of the planet. In 1889 Schiaparelli, an Italian astronomer, announced that he had discovered dark markings on the surface. However, down through the years the descriptions of the planet offered by various astronomers differ a great deal.

It is certainly safe to say that the surface of this planet has never been observed well enough so that we can be sure of its surface markings.

In the telescope Mercury exhibits a complete cycle of phases, just as the moon does. When the planet is between earth and the sun (inferior conjunction) the dark side is toward earth. When the planet is beyond the sun (superior conjunction) we see all the lighted half of Mercury. At all other times, the planet appears either as a crescent or as a gibbous moon—that is, somewhere between quarter phase and full.

Venus

Venus is the planet nearest to earth. At inferior conjunction it is only 26,000,000 miles from us, much closer than Mars ever comes to earth. But when the



Sunspots like these appear and disappear on the surface of the sun. The period 1958-9 was selected for the IGY study because it was a time of intense sunspot activity.

(Mount Wilson and Palomar Observatories)

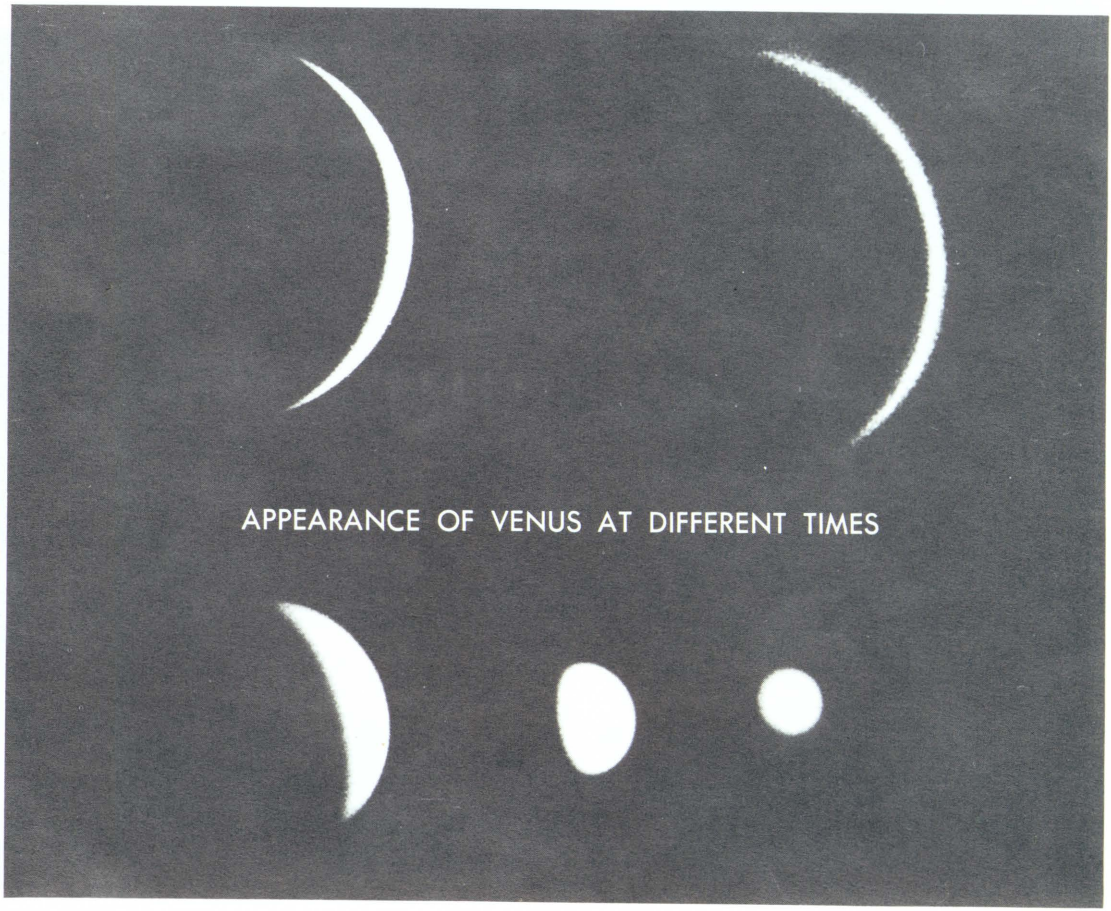
planet is on the far side of the sun (superior conjunction) it is 160,000,000 miles from earth.

Venus is by far the most brilliant planet in the sky. Sometimes it can be seen in full daylight. People of long ago saw Venus in the evening sky on certain occasions, and at other times they saw the planet in the morning sky. They thought that the planet was two entirely different stars, and so they gave the "two" objects separate names. The morning object was called Phosphorus and the evening object was called Hesperus.

Venus is often called earth's twin because it is like the earth in many ways —for example, its diameter is 7700 miles, very close to earth's. Also, the gravity of Venus is close to earth's gravity—a person who weighed 160 pounds on earth would weigh 138 pounds on Venus.

The mean distance of Venus from the sun is 67,270,000 miles, and so it must travel some 22 miles per second around the sun to hold its position. The time required for a complete revolution around the sun is 225 earth days—about two thirds of a year.

The surface of Venus has escaped observation, for the planet appears to be encased within an atmosphere that contains vast opaque clouds—formations



Note the similarity of appearance of Venus to that of the moon. But, note the wide variations in size. Why does the diameter of Venus always appear largest when its shape is a crescent?

(Lowell Observatory)

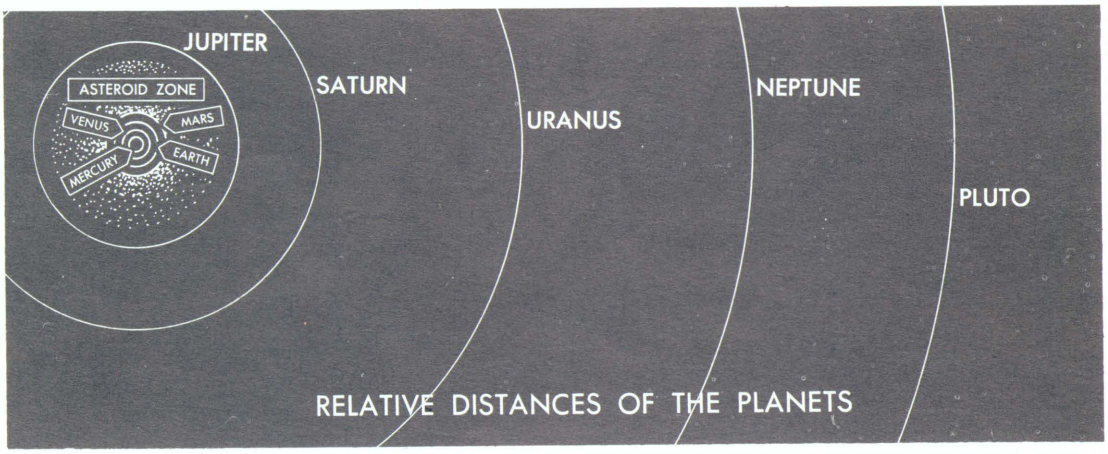
without breaks through which one might make occasional observations. Since the surface cannot be observed, and since there are no markings on the planet that are unchanging, it is quite impossible to determine the rotation period of the planet by optical means. By using the spectroscope, an instrument that can measure whether a light is moving toward you or away from you, astronomers have made measurements. These indicate that the planet may rotate once in three or four weeks. However, this figure is just an estimate. More information is needed before we can know the rotation period of Venus with any degree of certainty. Nevertheless, it is no doubt true that the rotation period of Venus is exceeded only by the period of Mercury.

We are positive that Venus has an atmosphere, for when Venus passes in front of a star, the star gradually disappears. Also, the starlight is bent. Both of these conditions indicate the presence of an atmosphere. The only substance that has been definitely identified in the atmosphere of Venus is carbon dioxide. The atmosphere of the earth also contains carbon dioxide, but not very much compared to that on Venus. The atmosphere of Venus contains 250 times more carbon dioxide than does the atmosphere of earth.

The fact that carbon dioxide is the only gas that has been identified does not mean that the atmosphere of Venus contains this gas alone. It may contain other kinds of gases, the amounts of which are not great enough to register on our instruments. Eventually we may develop more sensitive measuring devices which will indicate that other gases, such as neon, argon, nitrogen, water vapor, and others occur in the Venusian atmosphere.

Underneath the opaque atmosphere of Venus there is probably a solid surface, with a temperature close to that of boiling water. The hazy, opaque condition of the atmosphere is one of the puzzles of modern-day astronomy. The haze may be produced by suspended dust particles, but such an explanation is only an assumption; there are no observable facts to prove the possibility.

In 1959 Venus passed in front of the bright star, Regulus. This is the only time that Venus has done this since the invention of modern astronomical instruments. Observations made at that time confirmed the presence of an atmosphere, and gave indications that the atmosphere may be quite dense.



Comparative sizes of the orbits of the outer planets.

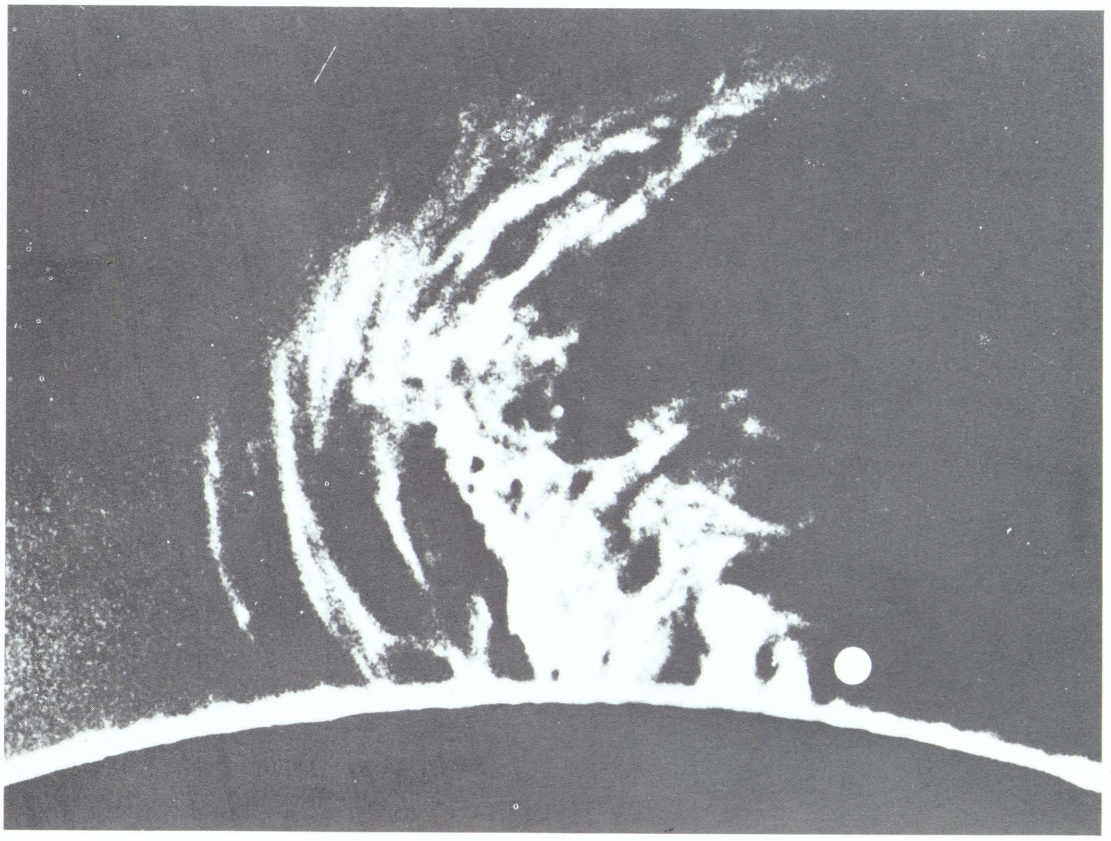
(The American Museum-Hayden Planetarium)

Earth

This is the planet of most importance to you and me. It is not a very impressive planet in size, for there are four planets smaller than earth—Mercury, Venus, Mars, and Pluto—and there are four planets larger than earth—Jupiter, Saturn, Uranus, and Neptune. Earth and the other small planets are often called the minor, or terrestrial planets. Each of them has a high density—that of earth is the highest of all. Its density is 5.5. This means that it weighs 5.5 times more than it would if it were composed of water.

Earth is about 7920 miles in diameter, and 24,880 in circumference. The planet is not spherical. It is flattened at the poles somewhat; the polar diameter is some 27 miles shorter than the equatorial diameter. In 1958-1959 it was found that the earth is slightly pear-shaped. There are depressions of some 50 feet in high latitudes, and the Antarctic region appears to be depressed about the same amount. Data that lead to these conclusions were obtained by observing Vanguard I, the small grapefruit-sized satellite that was launched in the spring of 1958.

The mass of earth is 6,000,000,000,000,000,000,000 tons. This is six thousand million million million tons. Scientists do not write out such numbers. They use a shorthand system. In this system, the number is written 6×10^{21} tons. It means that the 6 is



This *prominence* is an explosive storm of hot gas on the sun. The small white circle at lower right shows the comparative size of the earth.

(Mount Wilson and Palomar Observatories)

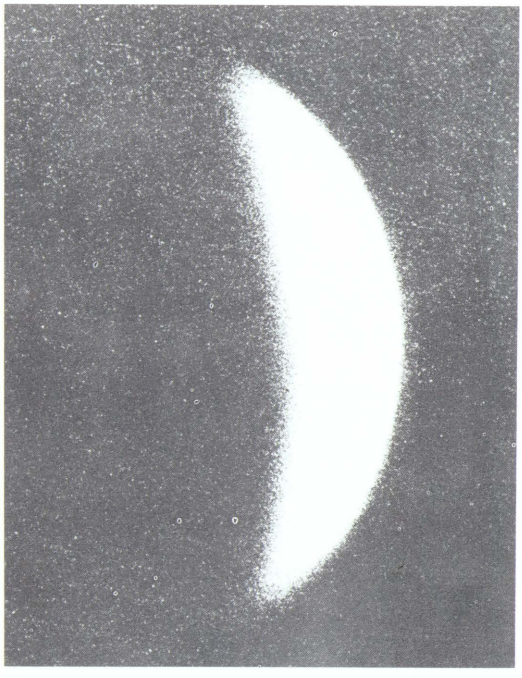
followed by 21 zeros.

The distance from earth to the sun varies because earth's orbit is elliptical. During summer in the Northern Hemisphere, earth is about 94,500,000 miles from the sun; during winter, earth is about 91,500,000 miles from the sun. When earth is nearest the sun, the planet moves fastest; when it is farthest from the sun, earth moves slowest. The mean speed of earth around the sun is 18.5 miles per second, or more than 66,000 miles per hour.

An earth day is the amount of time required for earth to turn around once on its axis. This is about twenty-four hours. As earth turns on its axis, the planet also goes around the sun, completing a revolution in a year. Earth rotates about 365 times while it is going around the sun. Thus, there are about 365 days in one year.

Earth exhibits other motions in addition to rotation and revolution. For example, the moon pulls on the earth as though exerting a constant effort to line up the axis with itself. Earth resists this force. As a result the axis of the earth swings slowly about, resembling the wobble of a spinning top. A line from the center of earth to the sky would scribe out a cone as a result of the moon's attraction on earth. The cone would be completed in some 26,000 years. As a result of this swinging about, the north axis of earth points toward different stars at different times. Many centuries ago Thuban was the star. Today the axis points toward Polaris (the present North Star). About 14,000 years from now the axis will point toward Vega. In 26,000 years Polaris will be the North Star once again.

In order to leave the earth or any of the other planets or their satellites, escape velocity must be attained. Escape velocity at the surface of the earth is 7 miles per second—about 25,000 miles per hour. This velocity has been attained on a number of occasions, whenever satellites and probes have achieved lunar or solar orbits.



The round shape of the earth's shadow during an eclipse of the moon shows that the earth itself is a round object. Can you get some idea from this photograph of the relative sizes of earth and moon?

(American Museum-Hayden Planetarium)

The Moon

The moon is earth's natural satellite. It is quite large, compared to the mother planet—some 2160 miles in diameter.

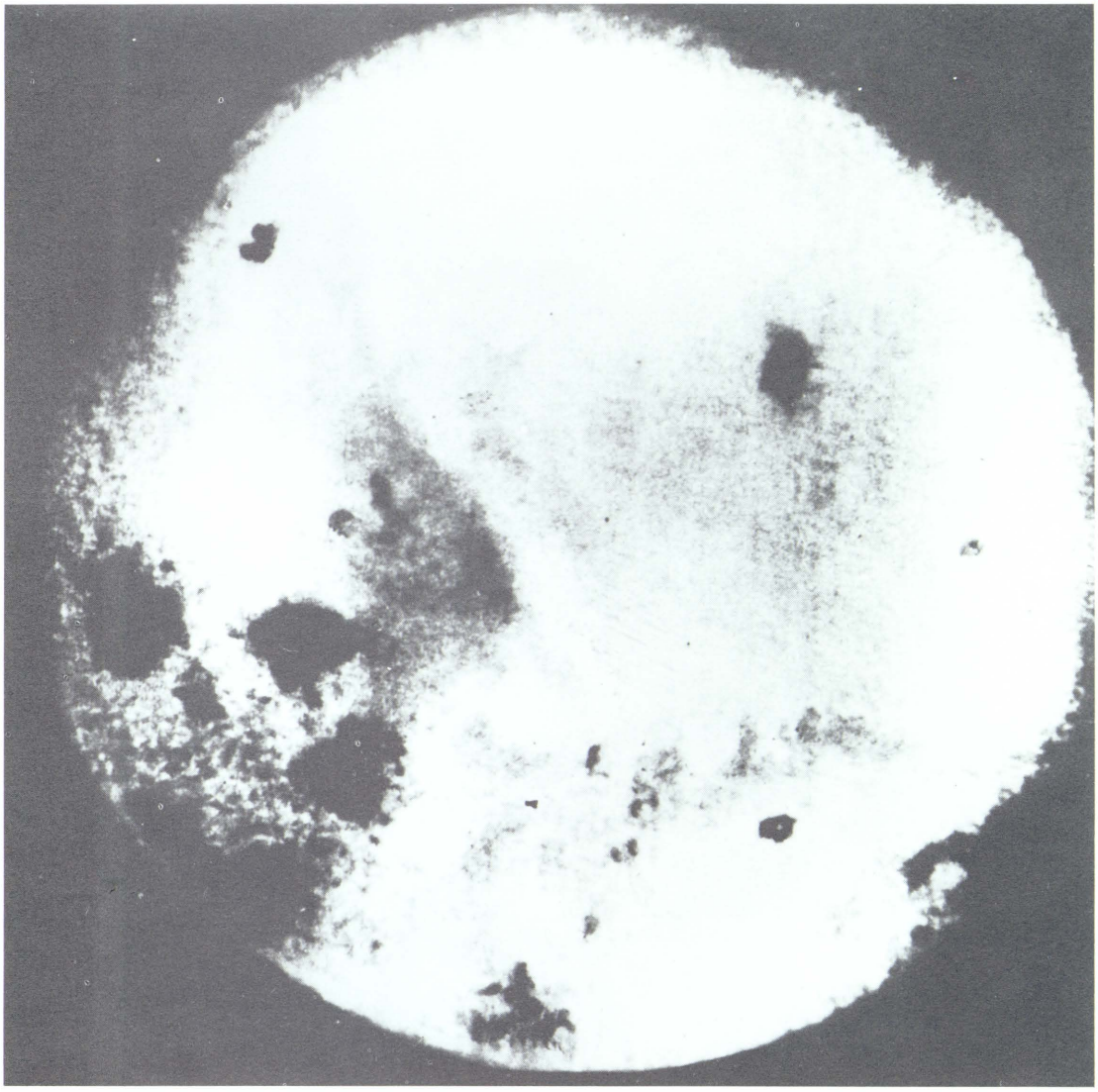
The effect of moon on earth that is most important is the tides. Without the moon, the sun would be the only tide-causing body. Because it is so far away, the tidal effect of the sun is not very great. The moon's gravitational attraction pulls the solid earth and the water on the earth. The water piles up, and so tides are produced. In some places, high tides are forty to fifty feet higher

View of the moon's surface. This photograph is actually a composite taken at two different times to reveal shadow detail. A full moon photo would appear quite flat and uninteresting because of the disappearance of most of the shadows in mountain areas.

(Lick Observatory, California)

This is how the moon would appear when a space ship comes in for a landing.

(The American Museum - Hayden Planetarium)

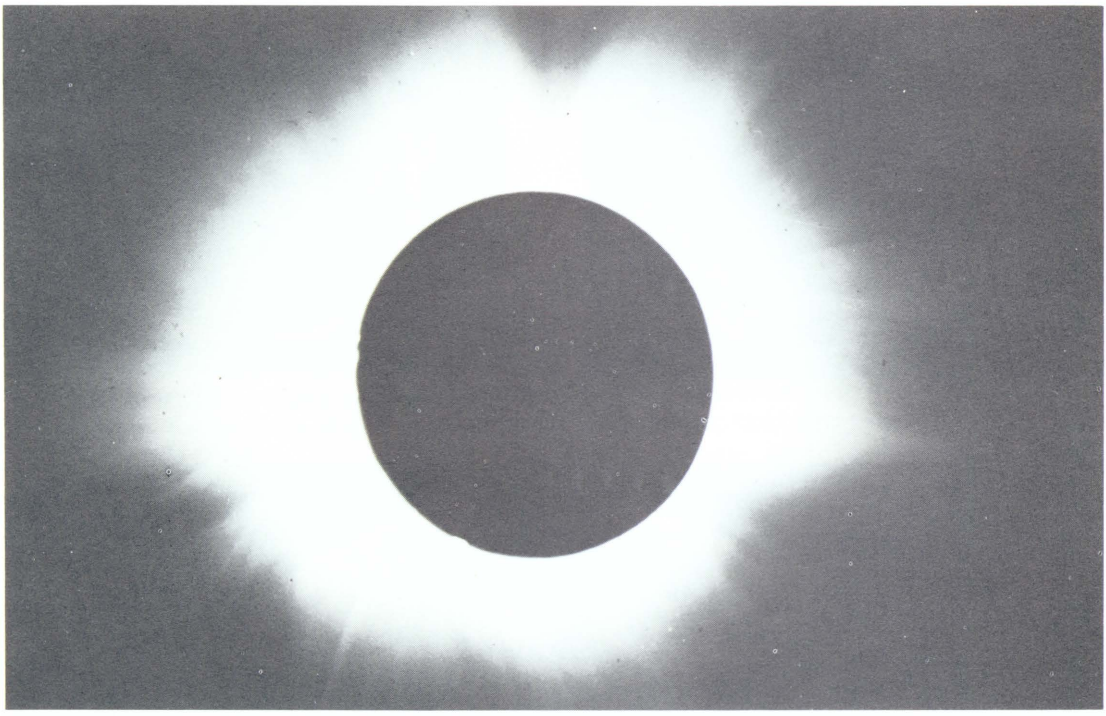


Historic photo of the back of the moon taken by the Russian Spaceship Lunik III, on October 7, 1959.
(Sovphoto, Moscow, USSR)

than low tides. However, such extremes are rare. It is not unusual at all to have a variation of five or six feet between low water and high water.

Many people have suggested that the moon affects weather. However, this statement is hard to believe, for most people who make it have not kept records and so their statements are little more than expressions of beliefs. You might keep records of moon phases and the kind of weather that accompanies the various phases. Perhaps if you keep your records long enough, you will find that there is a connection between the phase of the moon and the kind of weather that is experienced.

The phases of the moon are the apparent changes in the shape of the moon. In reality, the moon does not change shape. The moon goes around the earth, and so the angle made by the sun, earth, and moon is always changing. The moon is a sphere, and so one



During an eclipse of the sun, the moon (black circle) blocks out the direct light of the sun. A *corona* of glowing gas is then seen, extending for hundreds of thousands of miles around the sun.

(The American Museum - Hayden Planetarium)

half of the moon is always lighted by the sun. When the moon is between sun and earth, the lighted half is turned away from the earth and we cannot see it. This is new moon. An evening or so later, a thin crescent is seen in the west just after sunset. This is the waxing, or growing, crescent. A week later, the moon appears due south at sunset. This is the first quarter.

The moon appears to grow larger each night, and it also appears farther toward the east each night. When the moon is two weeks old (this means two weeks have elapsed since new moon), the moon rises in the east as the sun sets in the west. This is full moon.

Now the moon appears to become smaller and it rises later. When it is three weeks old, it rises about midnight, and it is in the third quarter phase.

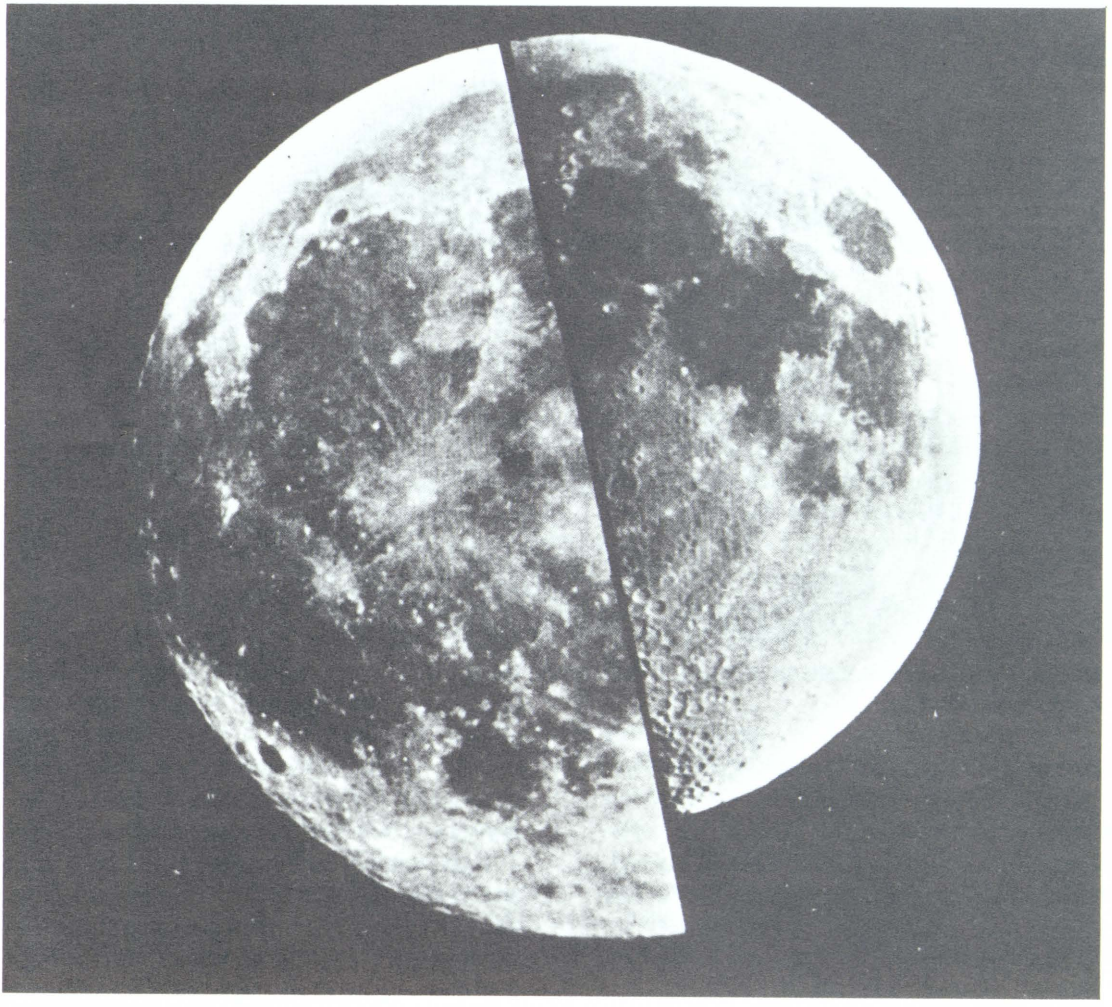
After about a month—29½ days—the moon is once again new, and the cycle of lunar phases begins again.

About half of the moon had never been seen until Lunik III photographed it, because the moon rotates and revolves in the same length of time—about 27⅓ days. To find how this causes us to see the same half continually, see the section on Mercury. To be more correct, we should say that 41 per cent of the moon has never been seen from earth. We can see slightly more than half of the moon because sometimes we can see a bit beyond the poles, or we can see a bit farther east or west.

Like most of the planets, and the other satellites, our satellite (the moon) is a dead world. There is no atmosphere on the moon. There is no water. Temperature changes are rapid and extreme. When the sun shines on the moon directly, the temperature may go to 215° F.—this is higher than the boiling point of water here on the earth. This

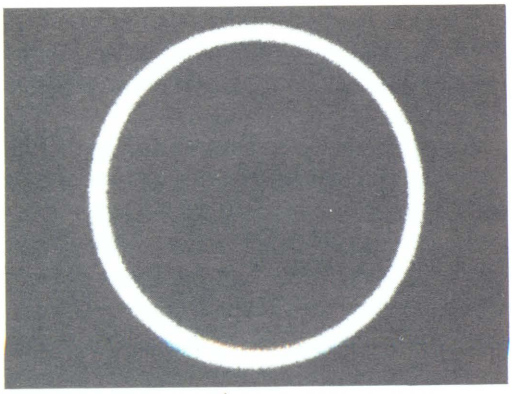
This long-exposure photograph of a crescent shaped moon reveals *earthshine* on the "dark" portion of the moon. Sunlight is reflected from the earth toward the moon and illuminates it. Some of this "earthlight" is reflected back to us to reveal a faint image. In this photograph the earthshine appears brighter than it really is because of the extra time exposure of the film. Note the planet Saturn to the right of the moon. Why is it oval shaped in this photograph?

(American Museum of Natural History)



Orbits of planets and satellites are eliptical (oval shaped) and not perfect circles. Thus, sometimes the moon is closer to us and at other times, farther away. This photo compares the sizes of the moon as it appears to us at the near and far points.

(The American Museum - Hayden Planetarium)



An *annular* (ring shaped) eclipse is observed when the moon is at the far point (apogee) of its orbit.

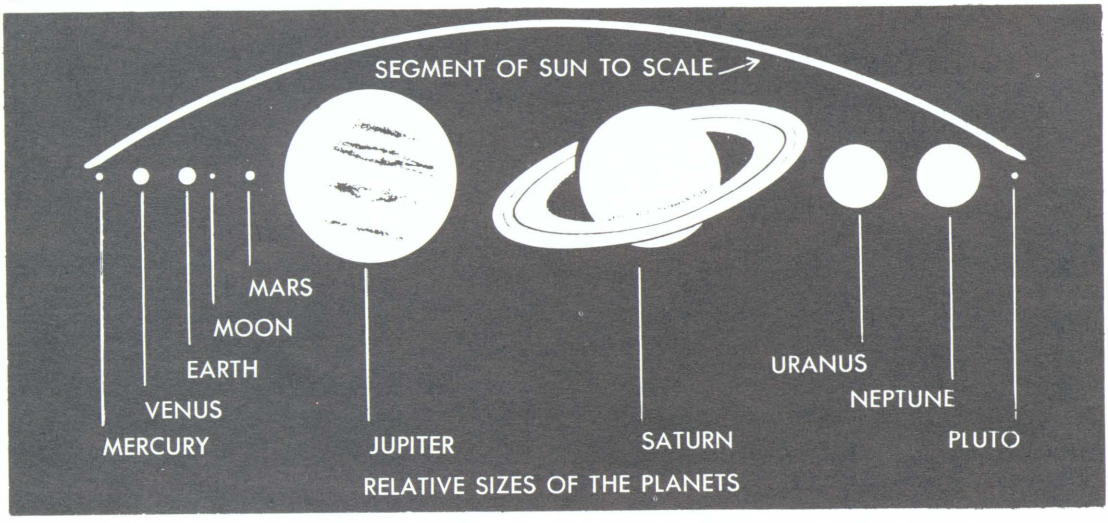
(American Museum - Hayden Planetarium)

same location becomes very cold when the sun does not shine upon it. The temperature may go to 250° F. below zero. That is much colder than any place here on earth. The coldest temperature recorded here was 125° F. below zero, about 70 miles from the South Pole.

The surface of the moon is made up of hundreds of different features, but the main formations are the craters and the mares (originally thought to be seas). Lunar craters vary in size from those so small we cannot see them, to great craters 60 to 70 miles across. About 30,000 of these craters have been identified. There must be more, for we cannot see anything on the moon that is less than 1300 feet across. The origin of the craters is still a great mystery. Some people believe that the craters were formed long ago when the moon might have been molten—somewhat like a soft plastic. They believe that great meteorites splashed into the moon and gouged out the craters. Other people believe that craters were formed by tremendous volcanoes, or series of volcanoes, that erupted when the moon was plastic and so the craters were larger than one would expect.

No one knows which theory is correct. Maybe the craters were formed in both ways. This is a question that may have to remain unanswered until man actually sets foot on this neighbor world. Even then, the answer may not be found, for the secrets of the beginnings of the moon may be locked away in the lunar rocks so securely that scientists will be unable to probe its mysteries.

The other basic lunar formations are the seas, or mares, of the moon. Early astronomers noted that some sections



Comparative sizes of planets, moon and the sun.

(The American Museum - Hayden Planetarium)

of the moon were very flat, like the surface of a sea, and so they called these flat regions seas. Of course, there is no water in them. More recent study of the seas of the moon indicates that they are not nearly so flat as people had thought. Crevices, rough areas, and a generally rolling landscape may be the more normal situation in these places. Nevertheless, when men reach the moon they will no doubt land in one of the mares, for the seas of the moon are much less treacherous than would be those places that are pockmarked with craters.

Mars

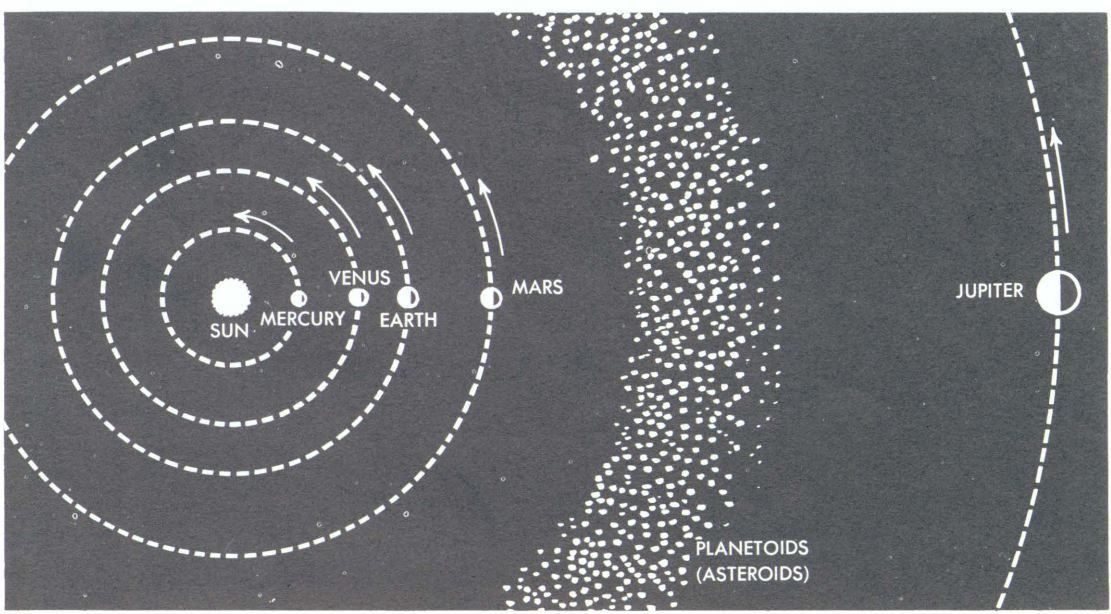
Mars is called the red planet because it often presents a reddish appearance. The mean distance of the planet from the sun is 141,690,000 miles, considerably more than our mean distance. Therefore, one would expect that Mars would be considerably colder than earth.

The average closest distance of Mars from earth is 48,700,000 miles. However, on occasion Mars is only 34,500,000 miles away.

Because Mars is so much farther from the sun than we are, the planet has a much longer year than we do. The year on Mars is 687 days—almost two of our years. The day on Mars is very close to our own; Mars completes a rotation in 24 hours, 37 minutes.

The diameter of the planet is only about one half that of earth—4221 miles.

The surface of Mars is the only planetary surface that astronomers have been able to study in detail. There are occasions when the surface can be seen very clearly for short periods of time, and numerous photographs that show variations in surface conditions have been made. No other planet has been seen so well. Perhaps fleeting glimpses of Mercury have been obtained, but no photographs that show surface condi-



Comparative sizes of the orbits of the 5 planets nearest the sun. Note the belt of the *planetoids* (also called asteroids), mainly between Mars and Jupiter. It is thought that these may be shattered remnants of an ancient planet.

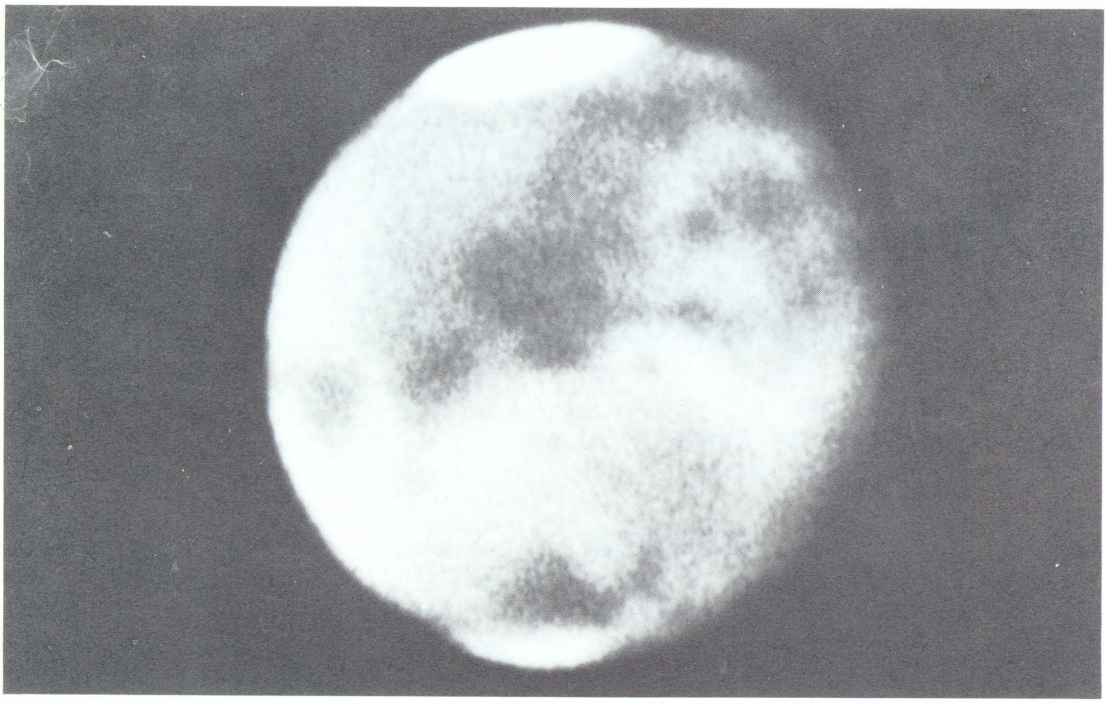
(The American Museum-Hayden Planetarium)

tions at all have been made. Venus and all of the major planets are covered with atmospheres through which we cannot see, and Pluto is so far away and so small that we could not hope to see it.

The reddish appearance of Mars may be due to red deposits of materials on large parts of the surface. The so-called deserts of Mars, the broad brown-red zones, may be covered with deposits of oxides. The oxides may be similar to iron rust here on earth. If the deposits are oxides, this would mean that at some time during its history the planet had a considerable amount of oxygen in its atmosphere. The oxygen would have combined with minerals, and so oxides resulted. This is just a theory, and there is no positive proof to support it.

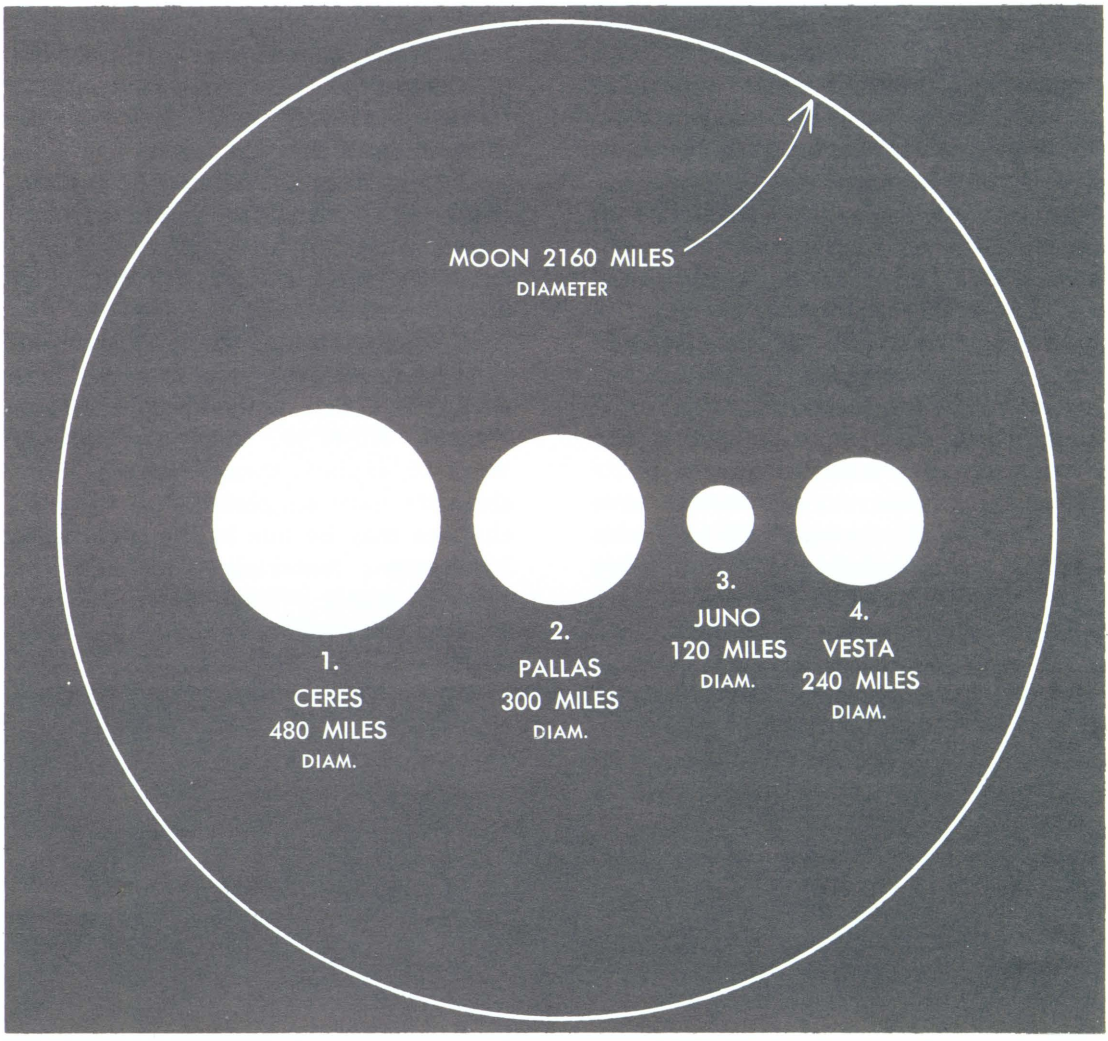
Many photographs of Mars reveal green sections. These green sections, some people believe, are areas covered by vegetation. In spring and summer the areas grow larger. They say that this indicates that the plants grow and so occupy more territory. In fall and winter the green areas decrease in size. These same people say that this indicates the plants die off with the advent of cold weather.

There is no doubt about the presence of these green areas, and they surely do change in extent as the Martian seasons change. However, there are different ways to explain these changes. Some chemists have suggested that the color changes may be due to the presence of hygroscopic materials — minerals that take in water. When these minerals take in water, they change color. Cop-



Note the snow caps of Mars at its north and south poles. Although some observers believe they see canals across the Martian surface, photographs do not show any. The blurred appearance of Mars in this photograph is due to bending of light by moving currents of air on the Earth during the lengthy exposure of the film. The snow caps change in size in accordance with changes in the tilt of Mars' axis toward the sun, in the same way that summer and winter occur on Earth.

(Dr. Kuiper, MacDonald Observatory, Texas)



Four bright asteroids (small planets) are compared in size with the moon. Most of the asteroids are very much smaller than the ones shown here. Their orbits are generally between those of Mars and Jupiter. A few approach rather closely to the earth during their revolutions around the sun.

(The American Museum-Hayden Planetarium)

per sulfate is a good example. Where copper sulfate lacks water, the substance is a white powder. When the white powder crystallizes with water, the substance is a deep blue. The surface of Mars may contain minerals of a similar type. At certain times, considerable water may be present—enough to cause a color different from the color that exists when the region is more arid.

The third feature of Mars that is very apparent are the polar caps. The substance in the caps has been analyzed, and it is known to be water in some form. The total amount is small—all the water on Mars could be contained in the basin of Lake Erie. The water in the polar caps is probably in the form of frost, or a thin layer of ice or snow.

The polar caps vary in extent. During summer, the caps decrease in size, and during winter they increase. This may be due to melting, a theory that has some support because some astronomers notice

a darkening of the edge of the cap. They suggest that the darkening may be due to wetting of the surface. Other astronomers suggest that the caps diminish because the ice, or frost, or snow changes directly to a vapor.

In any discussion of the planets, the question of whether or not there is life on Mars comes up. Because Mars has very little water, because the atmosphere is mostly carbon dioxide, because atmospheric pressure is very low, and because the planet is very cold in most locations, there is little possibility that life as we know it exists on this neighbor world.

There may be some kind of plant life, or there may be signs that some kind of life existed on the planet at a time when conditions were different than they now are. If there are plants, they would probably not be lichens, for lichens are rather high forms of life. A lichen is an alga and a fungus. The fungus dissolves salts and nourishment from rocks to which they cling. The alga, a green plant, uses the salts and minerals to manufacture food for itself and for the fungus. This is called a symbiotic relationship. If plants do exist on Mars, they would probably be lower forms of plant life than lichens. The lowest plants are those that exist in water. But, since there is little water on Mars, we would not expect such plants to flourish there. The plants of Mars, if any exist at all, may be quite different from lichens, or from any other kind of plant life that we know here on earth.

In one sense we know a great deal about Mars, because the planet has been observed by so many astronomers, and because so many photographs of it have been made. But, as is so often the case, even though we know a great deal about Mars, there is much that we do not know. This is still the planet of mystery.

The Satellites of Mars

Mars has two satellites. They are Phobos and Deimos, both of which were discovered in 1877 by Hall, an American astronomer. The satellites are very small, probably not more than 5 or 10 miles in diameter. They are rather close to the planet. Phobos, the inner satellite, is only 5000 miles away and Deimos, the outer one, is some 15,000 miles from the surface.

Phobos revolves very rapidly around the mother planet. In fact, it goes so fast that it makes three turns around the planet while Mars is making a single rotation. As a result, Phobos rises in the western sky and sets in the eastern sky, just the opposite of the rising and setting locations of our own satellite as seen from earth.

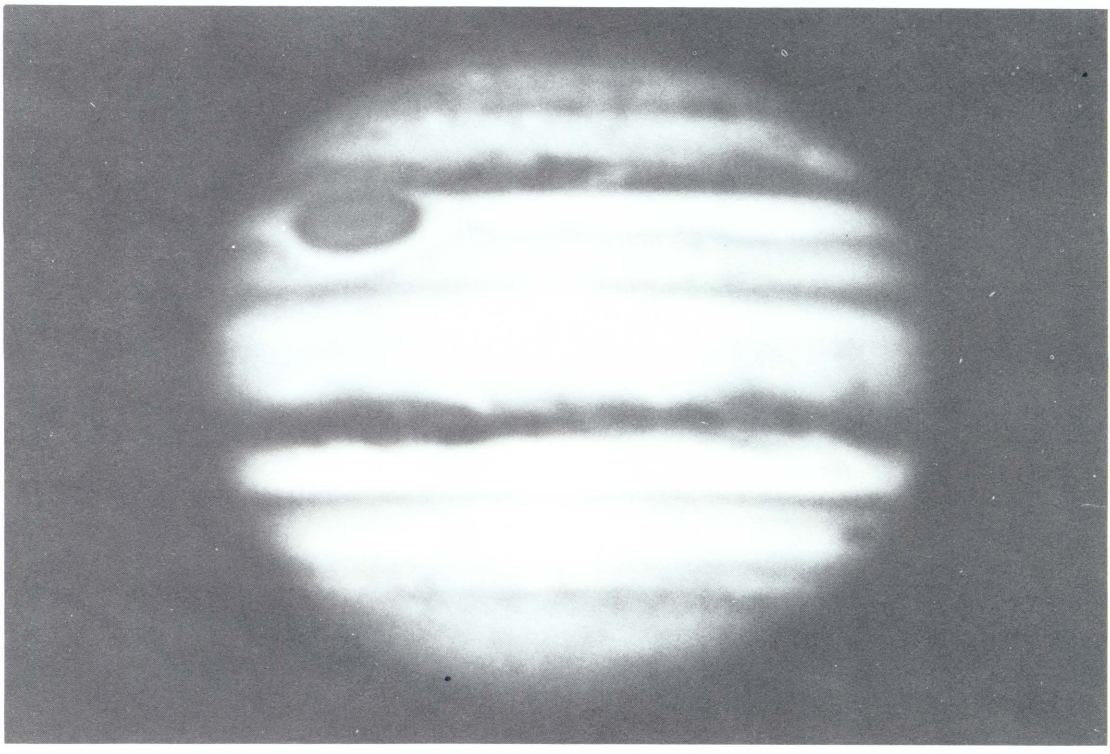
In 1959 it was suggested that the satellites of Mars may be artificial—that they may have been put into orbit by intelligent creatures of some sort. One reason for the suggestion was related to the motions of the satellites. Some observers said that they had measured changes in the orbit which indicated the satellites were accelerating and moving closer to the mother planet.

This theory, while interesting, was not accepted widely. Astronomers demand considerably more information than was available before they would accept such a startling idea.

Jupiter

This is the largest planet of the solar system. Its diameter from pole to pole is 82,800 miles, and 88,700 miles through the equator.

Jupiter moves some 8 miles a second in its orbit around the sun, completing the journey in nearly twelve years. The rotation of Jupiter is very rapid, for a day on this planet is only about ten hours. This is the shortest rotation period of all of the planets.



Jupiter's appearance is characterized by wide cloud bands. The only permanent feature is the *great red spot* (upper left) which changes in appearance from time to time. Note the bright area around the great red spot.
(Mount Wilson and Palomar Observatories)

A distinctive characteristic of Jupiter is the pattern of dark bands that appears all around the planet, which are generally parallel to the equator. The explanation of the dark bands has not been made. They may be produced by vast dust clouds suspended in Jupiter's atmosphere, or they may be produced by ice crystals. Perhaps neither of these possibilities is correct, and the dark bands may be produced by something entirely different. The details of the surface are ever-changing, therefore there must be considerable turbulence in the atmosphere of the planet. The shift of the surface markings is fairly uniform at times, which suggests there may be prevailing winds. The shifts are of such a nature that an atmosphere 300 to 500 miles deep is indicated.

The atmosphere of Jupiter is probably composed mostly of hydrogen. Our instruments detect the presence of methane and ammonia beneath the atmosphere. The ammonia must be mostly frozen — because the temperature is about 200° F. below zero — and so it would be in the form of tiny ice crystals floating in a gaseous envelope of hydrogen and methane.

As one goes deeper beneath the outer surface, the temperature probably is a bit warmer. But as pressure increases, as it does with depth, the gases would become mushy and ultimately they would be solid. The planetary surface has never been seen, of course, because the atmosphere is opaque.

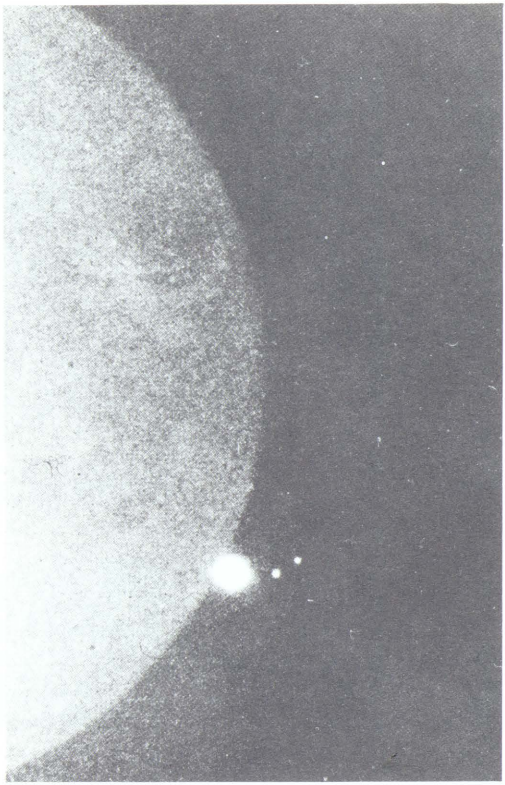
An astronomer by the name of Wildt has suggested what a cross-section of Jupiter may be like. His model is described briefly: the planet has a solid

core which has a radius of some 19,000 miles. Around the central core there is a shell with a thickness of 17,500 miles. This shell is composed of ice highly compressed because of the tremendous pressure that exists there. Another shell that envelopes the solid ice is composed of solid hydrogen. This shell is 8000 miles thick. This model is based upon careful computation, and it fits in well with our present knowledge of Jupiter. However, as our information about this distant world becomes greater, we may have to change the model considerably.

The Satellites of Jupiter

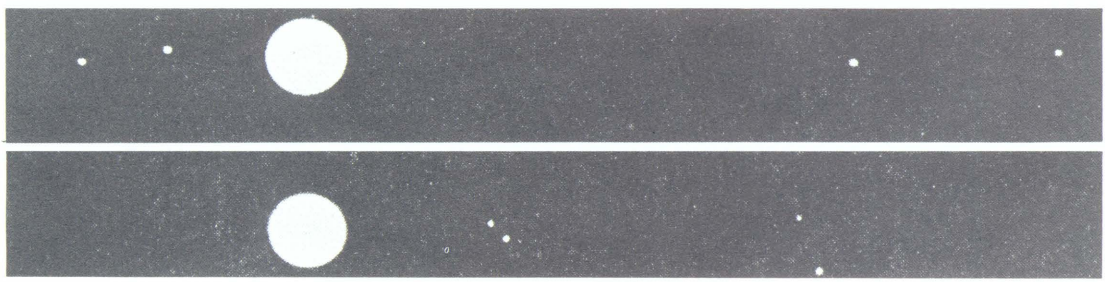
Altogether, Jupiter has twelve satellites revolving around it. Four of them are of particular interest because they were first observed by Galileo in the early seventeenth century.

At that time the Copernican theory of the nature of the solar system had been presented. The present-day conception of the solar system is an extension of this theory. But the Copernican viewpoint was not accepted because Copernicus, the Polish astronomer, could not prove that his ideas were correct. Therefore, Ptolemy's theory was still widely supported. A basic idea of this theory was that all objects in the universe moved around the earth. When Galileo observed the four satellites moving around Jupiter, he had evidence



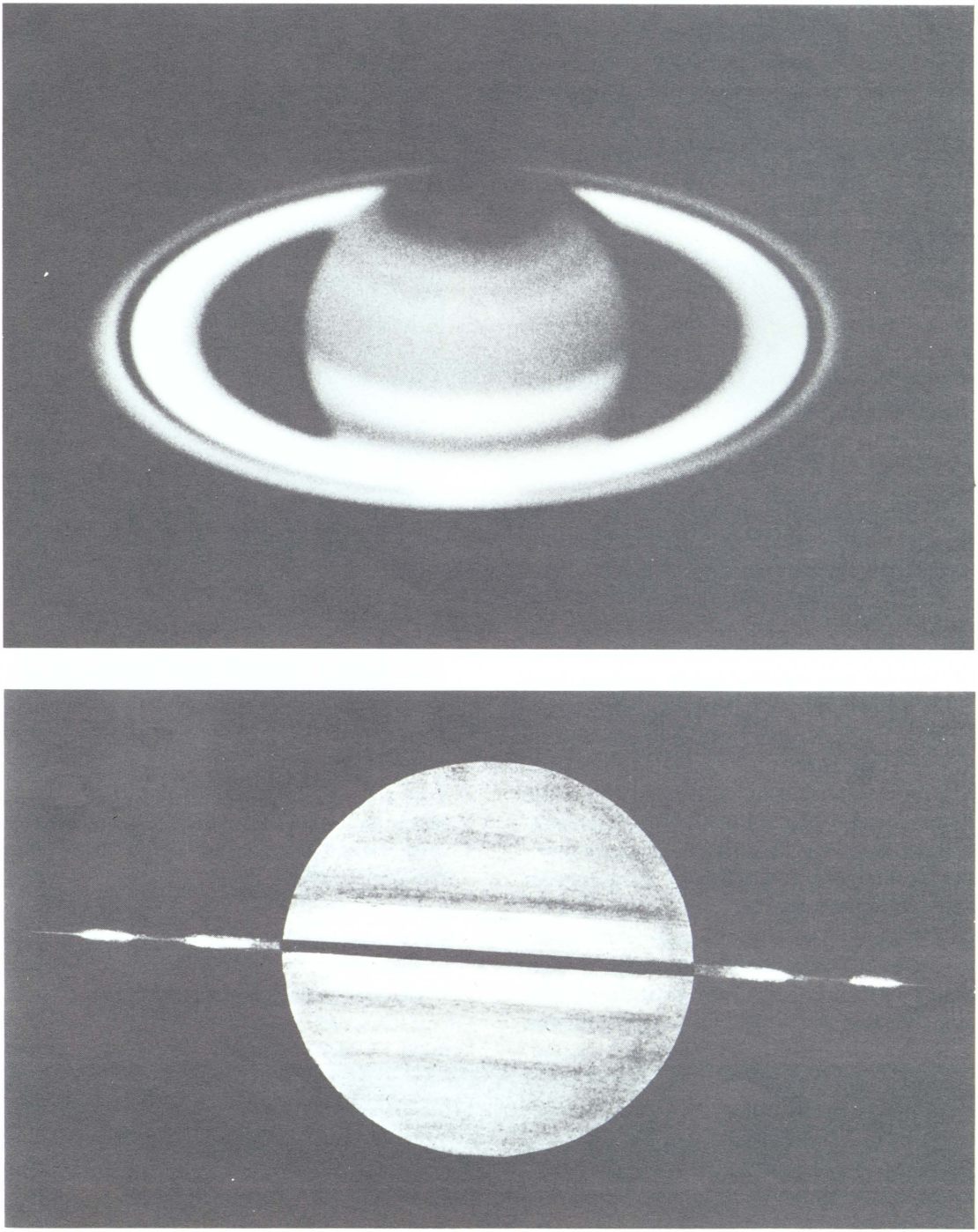
Does the moon have an atmosphere? This photograph of Jupiter and two of its moons emerging from behind our moon, indicates that there is little or no atmosphere on our moon. An atmosphere would bend and diffuse the light from the planets and stars, along its edge. The fact that there are no distortions in the appearance of such planets or stars shows that gases of an atmosphere are almost completely absent.

(American Museum - Hayden Planetarium)



Jupiter and its four largest moons shown on two different dates. Note that the moons revolve around Jupiter in orbits that are almost in the same plane, and that this plane is along the wide part of Jupiter.

(The American Museum - Hayden Planetarium)



Two different views of Saturn. The upper one is a photograph. The lower one is a drawing made by E. E. Barnard. Note the distinct groups of rings around the planet. Also, note the banded appearance of its atmosphere, similar to that of Jupiter. The rings are probably composed of large numbers of separate rock or ice particles in orbit around the planet. How do you explain the dark appearance of the ring against the planet, shown in the lower view?

(The American Museum - Hayden Planetarium)

that the basic principle of Ptolemy's theory was unsound. There were objects moving around bodies other than the earth, and this statement could be proved by observing through the newly-invented telescope. Now Ptolemy's theory began a sharp decline, and the Copernican viewpoint received ever-wider acceptance.

Saturn

Saturn is another giant planet. It is the second largest in the solar system —having a diameter of 67,000 miles from pole to pole and 75,000 miles through the equator.

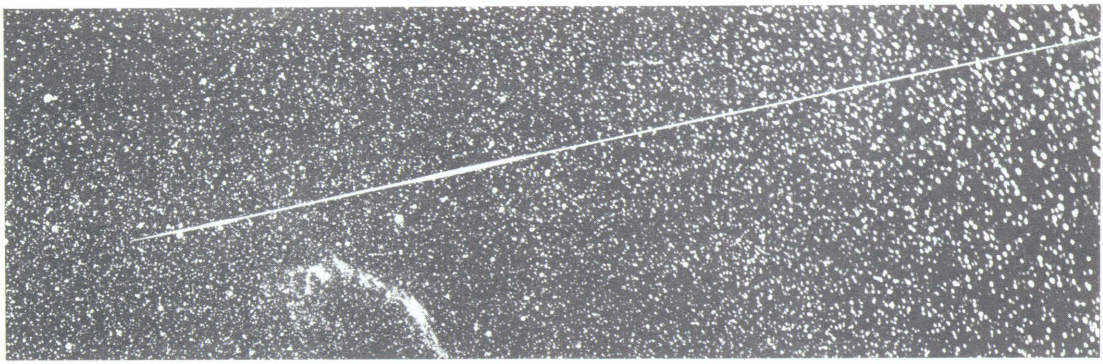
Like Jupiter, this planet spins around very fast, completing a rotation in slightly over ten hours.

It is believed that the structure of the planet itself is very much like that of Jupiter. Also, the materials that exist in the upper parts of the planet are methane and ammonia. Because it is far from the sun, the temperature of this planet is very low—around 240° F. below zero.

The most interesting feature of Saturn is its pattern of rings. These were seen first by Galileo in 1610, although he did not understand what they were. The rings were defined correctly much later, in 1675, by the Italian astronomer, G. D. Cassini.

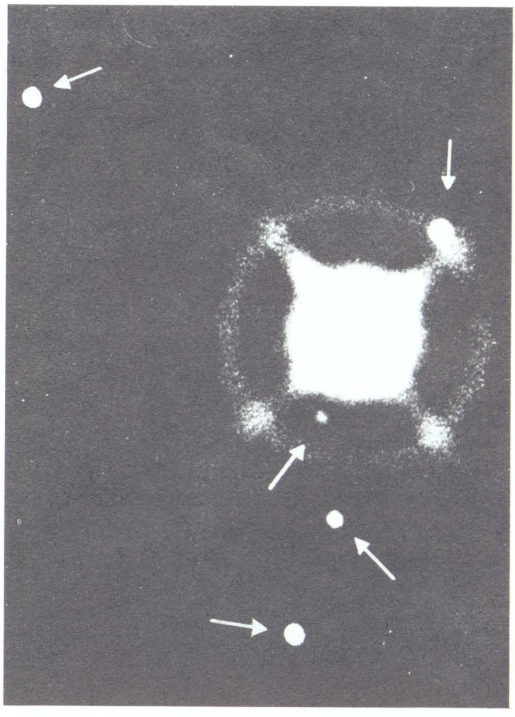
The outer ring is 170,000 miles across, and it is some 10,000 miles wide with a thickness of only about 50 miles. Within the outer ring there are two additional rings, making three in all.

The structure of the rings is not known. However, it is believed that the rings are made of discrete particles, that is, particles not fastened together. The particles may be rock-like in composition. Also, a large percentage of the particles may be ice crystals. The origin of the particles that comprise the rings is a great puzzle. Here again, suggestions have been made. Today, Saturn has nine satellites. It is possible that long ago the planet had a greater number of satellites. One, or more, of these additional satellites may have moved toward the mother planet, forced by the planet's gravitational attraction. The satellite may have moved close enough so that this force was great enough to shatter the satellite into small fragments. These fragments may then have become the particles that compose the rings. Once again, this explanation is little more than theoretical. When additional information is obtained, we may have to change our viewpoint entirely.



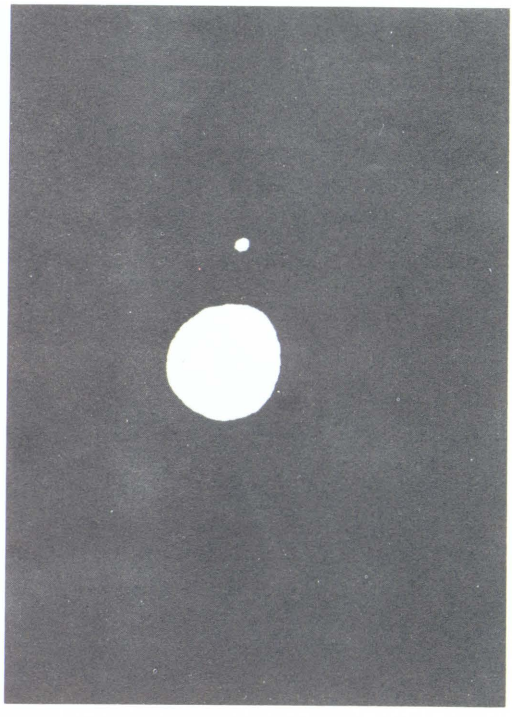
A "shooting star" (meteor) is a bit of material that shoots into our atmosphere at high speed and burns up in a few seconds. Photographs of meteors show streaks that widen and narrow and sometimes almost disappear for a time, as this one does.

(Yerkes Observatory)



Uranus and its satellites. Locate the 5 satellites shown in this photograph. The circular pattern and two crossed lines around Uranus are due to the structure of the supports for the inside of the telescope tube.

(American Museum - Hayden Planetarium)



Neptune and one of its satellites. The irregular appearance of the planet is due to irregularities in the motion of the telescope as it tracks the planet, and also to atmospheric disturbances on earth.

(American Museum - Hayden Planetarium)

Uranus and Neptune

These two planets, together with Jupiter and Saturn, make up the four major planets. Each of these planets is very large compared to the other planets of the solar system. Also, studies of each one of these planets reveal that they contain extensive amounts of methane and ammonia. The temperatures of each are very low and so the ammonia would be frozen out to some degree in all of the planets, and perhaps completely in the case of the outermost ones. Methane dominates in studies of Uranus and Neptune.

Uranus is some 1785 million miles from the sun. It moves about 4.2 miles per second, completing a journey about the sun in 84 years. It completes a rotation in slightly over ten hours.

Neptune is some 2797 million miles from the sun. It moves 3.4 miles per second in its journey around the sun, completing a revolution in 165 earth years. It completes a rotation around its axis once in about 16 hours.

Uranus has five satellites moving around it. Each of the satellites appears to be rather small; the largest probably having a diameter of only about 1000 miles.

Neptune appears to have two satellites. One of them, Triton, seems to have a diameter of about 3000 miles.

Neptune was discovered in 1846 as the result of calculations based upon the orbit of Uranus. The orbit of Uranus

did not quite fit the predictions. It was therefore assumed that an unknown planet's gravitational attraction was causing the "perturbation." The position of such an unknown planet was calculated and Neptune was found in the sky close to the place predicted for it.

Pluto

This is the outermost of the planets, some 3670 million miles from the sun. It moves some 3 miles a second around the sun, completing a revolution in 248 years.

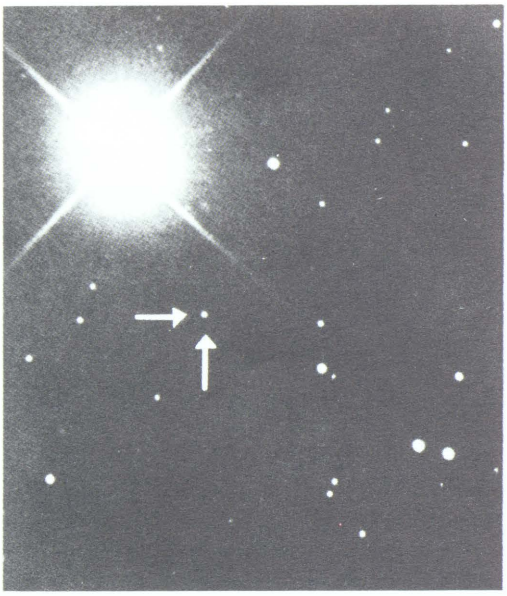
Pluto was discovered in 1930 at Lowell Observatory where Clyde Tombaugh, who was a student at the time, discovered the image of the planet on photographic plates. No other planets have been discovered since that time.

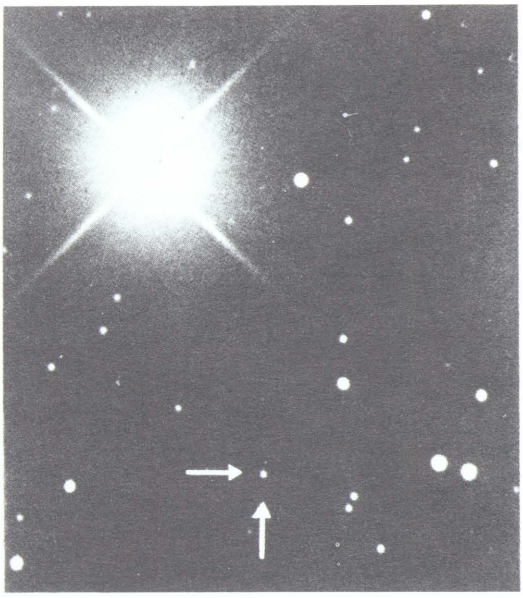
Because of its great distance from the earth, it is difficult to make observations of Pluto, and little is known about this planet. However, recent studies indicate that the planet rotates very slowly, taking over 6 days to make a complete turn.

Other Planets?

There may be other planets in our solar system, but the possibility is slim indeed. The chances are strong that if there are other planets they would have been discovered.

However, there may be other planetary systems associated with some of the other stars in our own galaxy. Many astronomers feel that there is considerable possibility that planets move around those stars which are similar to our sun in temperature, composition, and magnitude. Proof of such a belief may be a long time in coming, for the nearest star to our solar system is 4.3 light years away—some 26 million million miles. Right now, we have no way of spanning this distance well enough to pick up the weak light that such planets, would reflect to earth.



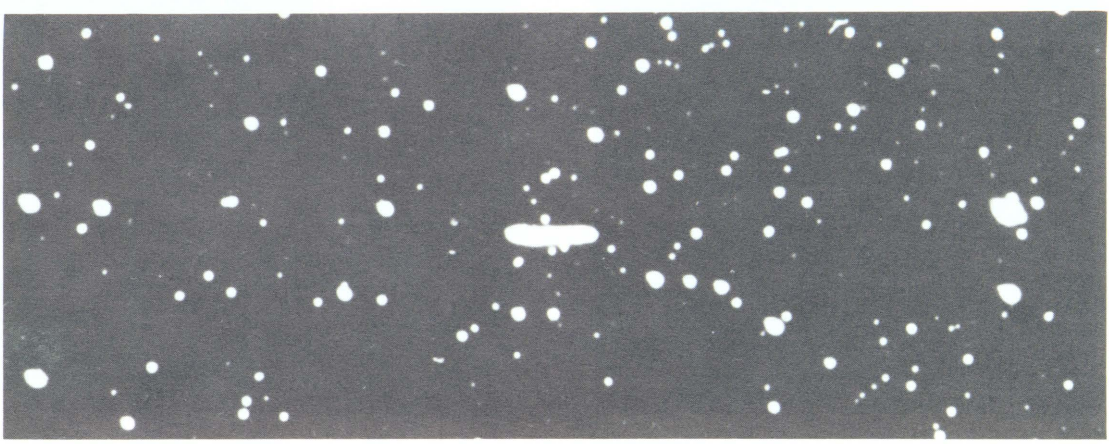


The planet Pluto was discovered from its change in position as shown in these highly enlarged photographs, taken about a week apart. The very slow motion in the sky of Pluto in comparison to the motions of planets or planetoids closer to us, is due to its great distance from the sun.

(The American Museum - Hayden Planetarium)

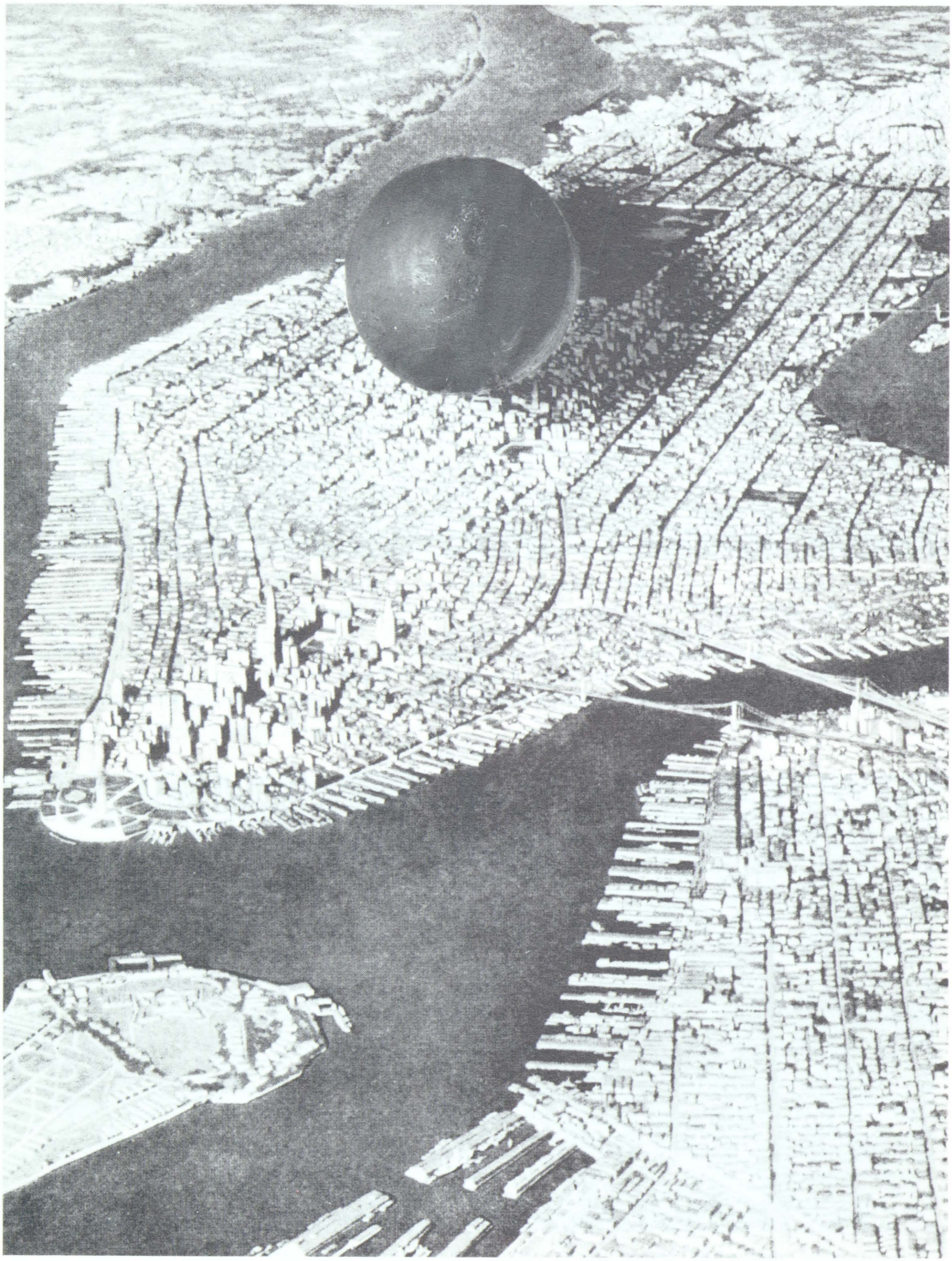
An astronomer traces the path of a planet or planetoid on a worksheet like this. Note the *retrograde* (reversed) motion of the planetoid. Such reversals are observed for all planets. Can you figure out why this happens?

(The American Museum - Hayden Planetarium)



Asteroids (planetoids) are discovered by the streaks that they produce when long exposure photographs are taken of portions of the sky. These streaks are due to the motion of the asteroid during the time of exposure.

(The American Museum - Hayden Planetarium)

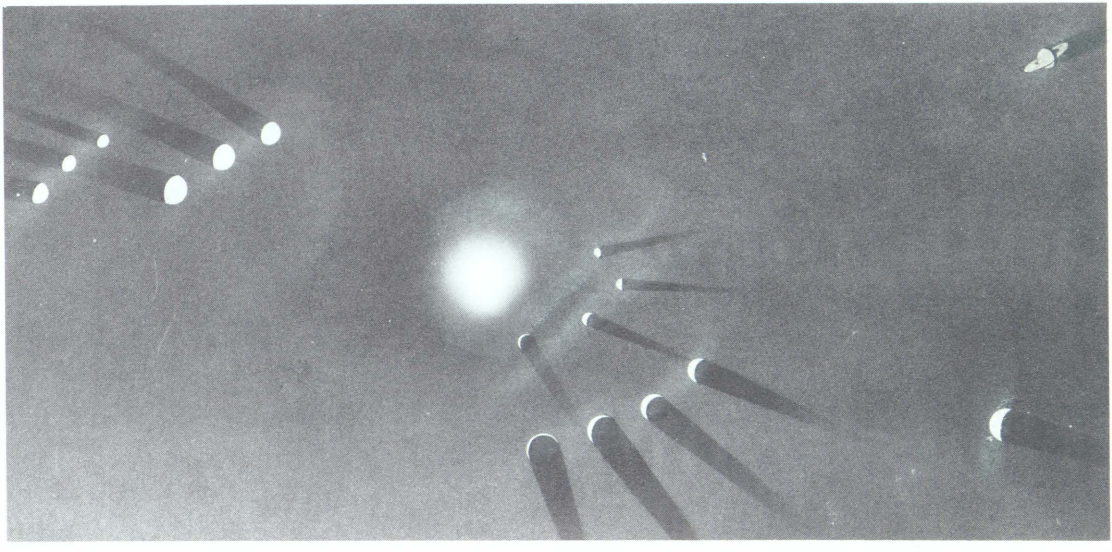


The asteroid Hermes is pictured against a photograph of New York City. What would happen if such an asteroid were to hit the earth?

(The American Museum - Hayden Planetarium)

Daniel's Comet as it appeared in 1907. Note the bright head and long streaming tail. Comets are loose masses of material in orbit around the sun. As they approach the sun, long streamer-like tails develop, always pointing away from the sun. These are caused by pressure of the sun's light which pushes the gases away from the comet's head. Bursts of streamers are sometimes observed from the comets. These are thought to be due to streams of particles shot out of the sun. These particles push the gases of the comet outward.

(The American Museum - Hayden Planetarium)



This drawing shows the approximate relative positions (from left to right) of Mars, Earth, Mercury, Venus, Jupiter and Saturn during October, 1958 (not drawn to scale). Can you figure out from this drawing, how each of the planets appeared from the earth at the time?

(The American Museum - Hayden Planetarium)

SATELLITES

IN ORDER OF DISTANCE FROM THEIR PLANETS

Earth
- Moon

Mars
- Phobos
- Deimos

Jupiter
- V
- Io (I)
- Europa (II)
- Ganymede (III)
- Callisto (IV)
- VI
- VII
- X
- XI
- VIII
- IX
- XII

Saturn
- Mimas
- Enceladus
- Tethys
- Dione
- Rhea
- Titan
- Hyperion
- Iapetus
- Phoebe

Uranus
- Miranda
- Ariel
- Umbriel
- Titania
- Oberon

Neptune
- Triton
- Nereid

No satellites are known for Mercury, Venus and Pluto.

For further reading:

Bernhard, Bennett and Rice

New Handbook of the Heavens, McGraw-Hill Book Co., Inc., New York.

Branley, Franklyn M.

The Nine Planets, Solar Energy, Experiments in Sky Watching, The Moon — Earth's Natural Satellite, Mars, Thomas Crowell Co., New York.

Gallant, Roy A.

Exploring Mars, Exploring the Moon, Exploring the Planets, Exploring the Sun, Exploring the Universe, Garden City Books, New York.

Ruchlis, Hy

Orbit, Harper & Brothers, New York.

Wyler, Rose, and Ames, Gerald

Golden Book of Astronomy, Golden Press, New York; *First Days of the World,* Harper & Brothers, New York.

Zim, Herbert S.

Shooting Stars, Wm. Morrow & Co., New York.

PLANETS

	MEAN DIAMETER (MILES)	ROTATION PERIOD	MEAN DISTANCE FROM SUN	PERIOD OF REVOLUTION
MERCURY	3,010	88 d.	36.0 million miles	88.0 d.
VENUS	7,610	30 d. ?	67.2	224.7 d.
EARTH	7,918	23 h. 56 m.	92.9	365.3 d.
MARS	4,140	24 h. 37 m.	141.5	687.0 d.
JUPITER	86,900	9 h. 50 m. ±	483.3	11.86 y.
SATURN	71,500	10 h. 02 m. ±	886.0	29.46 y.
URANUS	29,500	10 h. 50 m. ±	1,783.0	84.01 y.
NEPTUNE	26,800	15 h. 50 m. ±	2,791.0	164.80 y.
PLUTO	3,600	6 d. 6 h.	3,671.0	248.40 y.

m.—minutes h.—hours d.—days y.—years

Astronomy Projects and Problems

1. The photograph on Page **16** shows the moon as it appears at the far point of its orbit (apogee) and at the near point (perigee). Calculate from these photographs the ratio of distances of the moon at perigee and apogee.

2. A similar situation to that posed in #1 is suggested by the annular eclipse shown on Page **17**. Can you pose a problem dealing with this photograph and make measurements to solve it?

3. Is the moon perfectly round? Make measurements of the photographs of the moon in this and other books. What do you conclude?

4. Is the sun perfectly round? Make measurements of the photographs of the sun in this and other books. What do you conclude?

5. From the photograph of the lunar eclipse on Page **11**, obtain an estimate of the size of the moon in comparison with the 8,000 mile diameter of the earth.

6. Note the several bright indentations along the circumference of the moon during the solar eclipse shown on Page **15**. How would you explain these bright indentations? Set up an experiment to duplicate the situation.

7. Calculate the relative diameters of sun and earth from the information pictured in the illustration on Page **10**.

8. One way to measure the distance to the moon is to bounce a radio wave off its surface and pick up the reflected wave. If the radio wave returns in 2.4 seconds, how far away is the moon? (Light travels at a speed of 186,000 miles a second.)

9. Measure the diameter of some of the larger craters of the moon as shown in the photographs in this book. Assume that the diameter of the moon is 2,160 miles.

10. Examine the shadows in the photograph of the moon on Page **12** and prove that it is a composite of photographs taken at two different times.

11. Carefully study the photograph of the moon on Page **13**. Describe different types of features of the moon's surface that are revealed in this picture.

12. Make a chart that shows the cause of the phases of the moon.

13. Make a chart comparing the sizes of the planets. Draw them to scale or use balls of the proper size.

14. Make a chart showing relative sizes of planetary orbits.

15. Obtain an estimate of Mercury's size in comparison with the sun using information obtained from the photograph on Page **4** and the planetary distance tables in this book.

16. Answer the following questions about the relative positions of the planets shown in the drawing on Page **30**:

A. Approximately where would each of the planets appear to be in the sky just after sunset?

B. What would be the shape of each planet, as seen from the earth?

C. Why is only one position shown for Jupiter? For Saturn?

D. According to this picture, which planet travels fastest?

17. Estimate the approximate relative size of the orbit of Venus to that of the earth by measuring the shapes shown on Page 8 .

18. Study the photograph of Jupiter on Page 22. Assume that the diameter of Jupiter is 80,000 miles across at its wide part. Then answer these questions:

A. How wide are the dark bands?

B. How large is the "great red spot"?

C. How does the north-south diameter of Jupiter compare with the diameter at the equator?

D. What evidence do you note that Jupiter rotates rapidly?

E. Develop a hypothesis (theory) to explain the great red spot and the bright area around it.

19. Study the photograph of Jupiter and its moons on Page 23. Develop a hypothesis to explain why the plane of the orbits of the moons and the wide diameter of Jupiter almost coincide.

20. Study the pictures of Saturn on Page 24. Measure and analyze the structure of the rings. Why does the ring in the lower photograph appear dark when Saturn is in the background?

21. Study the photograph of the meteor on Page 25. Develop a hypothesis to explain the disappearance of the meteor streak. Use a ruler to find out whether the path of the meteor appears as a straight line or not. How do you explain your observation?

Advanced Projects

22. *Measure the dimensions of lunar mountains.*

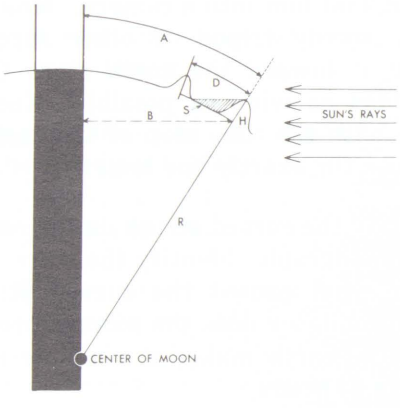
Study the photograph on Page 13. By comparison of shapes, locate the mountains in this enlarged photo with respect to the smaller scale photo of Page 12. Select a larger crater near the dark edge, one that has a distinct shadow. Then do the following:

A. Use an accurate centimeter ruler. (Why?). Measure the diameter of the crater (d) on the photograph. Compare it with the moon's diameter (2,160 miles). Use the longest diameter of the crater. (Why?). Then calculate the width of the crater.

B. Measure the length of the shadow of the crater in the same way.

C. Measure the distance (A) of the crater edge to the beginning of the dark (night) region of the moon. This distance is approximately equal to B. (Why?). Then the height (H) of the mountain is given by $\frac{H}{S} = \frac{B}{R}$ (Why?)

Using the fact that the radius (R) of the moon is half of 2,160 miles, and, using the measured distances S (shadow) and B, calculate the height of the mountain.



23. *Track a planet through the sky.*

The drawing on Page 28 is a worksheet of an astronomer as he traced the path in the sky of the Asteroid Vesta from May 29, 1935 to December 31, 1935. Note the "retrograde" motion of the asteroid as it reverses its apparent motion in the sky.

Make a large horizontal chart of the orbits of Earth and Mars. Locate the positions of both planets at the time you make the chart as obtained from astronomical charts or tables (obtainable from Sky Publishing Corporation, Harvard College Observatory, Cambridge 38, Massachusetts).

Locate the monthly positions of each planet thereafter for at least one complete revolution of Mars around the sun (about 4 years).

From this chart, predict the positions of Mars in the sky at different times. Predict when and where the retrograde motions will occur. Check your predictions with actual observations. For this purpose it will suffice to take simple photographs of the region around Mars with an ordinary camera and without a telescope.

Do the same with other planets.

24. *Verify the rotation of the earth.*

Put fast film into a camera. Mount it on a sturdy tripod or other support. Point it toward the north star. Open the lens as wide as possible. Keep it open with the time stop of the camera. Expose for exactly one hour.

Study the curved streak on the resulting photograph. Identify the stars. Explain what caused the curved streak. What evidence does the picture provide that the earth makes a complete rotation in 24 hours?

25. *Measure, by means of actual observations, the period of revolution of the moon around the earth.*

26. *Calculate the distance of Venus from the sun.*

Observe the planet Venus in the sky. By means of actual observation during one year, estimate its period (time of revolution) around the sun. Take into account the motion of Earth around the sun while Venus revolves.

Then, calculate the distance of Venus from the sun using Kepler's Third Law: *"The squares of the periods of any two planets are in the same proportion as the cubes of their mean (average) distances from the sun."*

27. *Measure the distance to the moon.*

Arrange with a student in a country somewhere near the opposite side of the earth to photograph the moon at the same moment. (How would you do this?) Expose the film long enough to record nearby stars. Exchange photos. The moon will appear in both photographs to be in somewhat different portions of the sky. This is due to *parallax*. From the distances between the two places and the amount of parallax you can compute the distance of the moon.

This may also be done by photographing the moon from the same place at different times of the night. But in that case, you must take into account the motion of the moon during the interval.

28. *Measure the diameter of the earth.*

Read about how the Greek scientist Eratosthenes measured the diameter of the earth about 2,000 years ago. Arrange with a person who lives 500 to 1,000 miles north or south of you to measure, on the same day, the dimensions of the shadow of a stick at true

noon. Obtain the distance between places from a map. Then compute the circumference of the earth.

29. *Measure the distance of an object about a quarter mile away by measuring the angles to it from a known base line.*

This is essentially the method of measuring distances to objects in the solar system and the closest stars.

30. *What is your latitude?*

Measure the angle of the North Star above the horizon. Take into account the fact that the North Star is not exactly above the North Pole of the earth.

31. *Measure your longitude.*

Tune in on a British radio station at about noon in your area. Obtain the difference in time between England (0° longitude) and your area.

Measure the exact time that the shadow of a stick is shortest. This will usually not occur *exactly* at 12:00 noon.

From the above information you can obtain a fairly accurate calculation of your longitude.

32. *Make a reflecting telescope.*

33. *Take photographs of the sun.*

Use special filters to cut out most of the light. These photographs may be used to measure the sun's rate of rotation. Does the sun rotate at the same speed at the poles as at the equator?

Make a study of sunspots based on these photographs.

34. *Take photographs of the moon, Venus, Jupiter and Mars.*

Use very fast, fine grain film and special developing technique to increase the speed of the film and clarity of the image. Use a camera with a wide lens. The larger the size of the film the larger will the image be.

Enlarge the resulting negatives and study the detail you can see. Make a display of these photographs.

35. *Attach a camera to a good telescope and take photographs of planets, the moon and stars.*

36. *Make a detailed study of the moon's features from large photographs obtainable from observatories.*

37. *Study the moon by telescope* and note whether or not, as it moves in front of a star, it blocks it from view suddenly or gradually. Note the same thing about stars that come into view as the moon passes by. Make measurements of the rate of motion of the moon through the sky.

38. From the known distances of the planets from the sun and their periods of revolution, *compute their speeds of motion around the sun.* (Assume that the orbits are circular.) Do the same for the speed of motion of the moon around the earth.

39. *Build a motorized model of the earth, moon and sun* to show their motions.

Do the same for the planets.

40. *Observe the moons of Jupiter* several hours during one night.

Do you note any evidence of motion of the satellites? Make a study of their positions for a week or so and measure their periods of rotation.

41. *Meteor showers* occur during certain periods of the year.

The Perseids begin around the mid-

dle of July and last until mid-August, with a maximum on August 11. The Orionids have a maximum on October 20th, and the Geminids on December 10th. The "shower" is revealed by increased frequency of occurrence of the meteor flashes in the sky. Study directions of the meteors observed on or about these dates and show that each shower has its own point of origin from which the meteors seem to come in the sky. Find out why this happens.

Suggested Reports for Schools and Clubs

1. Radio telescopes
2. Reflecting (mirror) telescopes
3. Eclipses of the sun
4. Eclipses of the moon
5. Orbits
6. Auroras
7. Earthshine
8. Craters of the moon
9. Phases of the moon
10. Phases of Venus and other planets.
11. Craters on earth caused by giant meteorites
12. The changing calendar
13. Mercury
14. Venus
15. Mars
16. Asteroids (or planetoids)
17. Jupiter
18. How did Roemer measure the speed of light from observations of Jupiter's moons?
19. Uranus
20. Neptune (particularly the way in which it was discovered.)
21. Pluto
22. Comets
23. Meteors and meteorites
24. Earth satellites
25. Is there life on other planets?
26. Stars
27. Galaxies
28. Problems of Space Flight